

# 313 new asteroid rotation periods from Palomar Transient Factory observations

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## ABSTRACT

A new asteroid rotation period survey have been carried out by using the *Palomar Transient Factory* (PTF). Twelve consecutive PTF fields, which covered an area of  $87 \text{ deg}^2$  in the ecliptic plane, were observed in  $R$  band with a cadence of  $\sim 20$  min during February 15–18, 2013. We detected 2500 known asteroids with a diameter range of  $0.5 \text{ km} \leq D \leq 200 \text{ km}$ . Of these, 313 objects had highly reliable rotation periods and exhibited the “spin barrier” at  $\sim 2$  hours. In contrast to the flat spin rate distribution of the asteroids with  $3 \text{ km} \leq D \leq 15 \text{ km}$  shown by Pravec et al. (2008), our results deviated somewhat from a Maxwellian distribution and showed a decrease at the spin rate greater than 5 rev/day. One super-fast-rotator candidate and two possible binary asteroids were also found in this work.

*Subject headings:* surveys - minor planets, asteroids: general

## 1. Introduction

Time-series photometry is a powerful tool to derive physical properties of solar system objects including the rotation periods and shapes of asteroids and cometary nuclei. Harris (1996) showed a “spin barrier” at 2.2 hours for asteroids with  $D \gtrsim 1$  km, which indicates large asteroids are gravitationally bounded aggregations (i.e., rubble-pile structure). Following that study, Pravec & Harris (2000) revealed that the asteroids with diameter larger than a few hundred meters are rubble-piles and have spin rates lower than the “spin barrier”, while smaller asteroids may rotate faster than the “spin barrier” (i.e., super-fast-rotator; see an example study of Hergenrother & Whiteley 2011) and are likely monolithic objects. Exceptions to this rule are rare. For example, 2001 OE84 has a diameter of 0.9 km and a rotation period of 29.19 min (Pravec et al. 2002). Subsequently, Holsapple (2007) suggested a size-dependent strength for asteroids and predicted the existence of kilometer size super-fast-rotators. Moreover, the spin rate distributions of different size asteroids are useful to investigate how different mechanisms alter the asteroid rotations. Salo (1987) showed that a collisionally evolved asteroidal system should have a Maxwellian spin rate distribution. This is true for asteroids with  $D > 40$  km (Pravec et al. 2002). However, mechanisms in addition to collision, in particular the Yarkovsky-O’Keefe-Radzievskii-Paddack (YORP; Rubincam 2000), create excesses both at the very slow and fast ends for smaller size asteroids (Pravec et al. 2002; Polishook & Brosch 2008; Masiero et al. 2009).

While this information is of importance in establishing the global property of the asteroids, only a small fraction ( $\sim 4000$  among  $\sim 620000$  known asteroids) have published lightcurves and rotation periods (Warner et al. 2009). In recent years large field of view surveys have been used to study asteroid rotation periods (see examples of Masiero et al. 2009; Polishook et al. 2012). With the increasing volume of such data sets, the studies of

the asteroid rotation properties (i.e., spin rate limit and spin rate distribution) can be done as a function of different taxonomic types, dynamical groups and asteroid families.

As demonstrated by the pilot work of Polishook et al. (2012), the asteroidal observations in the *Palomar Transient Factory* (PTF) synoptic survey could make important contributions in this respect. They reported their analysis of four overlapping PTF fields covering  $21 \text{ deg}^2$  with multiple observations ( $\geq 10$  images) per night and a typical cadence of  $\sim 20$  min. Of the 624 asteroids detected in their work, 88 of them have well-determined rotation periods and 85 have low quality rotation periods. Here, we continue this line of work by presenting 312 new, high quality, asteroid rotation periods. The final goal of this long term project is to collect a sample of about  $\sim 10^4$  asteroid rotation periods.

In Section 2, the observation information is described. The method of data analysis is given in Section 3. The results on the statistical distribution of the rotation periods and the properties of some individual asteroids are presented in Section 4. A summary and conclusion can be found in Section 5.

## 2. Observations

The PTF<sup>1</sup> is a synoptic survey designed to explore the transient and variable sky (Law et al. 2009; Rau et al. 2009), which employs the 48-inch Oschin Schmidt Telescope equipped with a 11 chips mosaic CCD camera (i.e., the former CFHT-12K camera, in which the chip no. 3 is out of function). The available filters include Mould-*R*, Gunn-*g'* and  $H_\alpha$ . Such a configuration has a field of view of  $\sim 7.26 \text{ deg}^2$  and a pixel scale of  $1.01''$ . The  $5\sigma$  median limiting magnitude of an exposure of 60 s in *R* band is  $\sim 21$  mag (Law et al. 2010).

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<sup>1</sup><http://ptf.caltech.edu>

As part of the Ten Thousand Asteroid Rotation Periods project (10kARPs), twelve consecutive PTF fields, which covered an area of  $87 \text{ deg}^2$  on the ecliptic plane, were observed in  $R$  band with a cadence of  $\sim 20$  min during February 15–18, 2013. The exposure time of each image was 60 s. Fig. 1 shows the field configuration and Table 1 lists the observation information. Since this campaign was dedicated to the study of Galactic variables as well, our target fields were close to the Galactic plane.

### 3. Data Analysis

#### 3.1. Data Reduction and Photometry Calibration

Each PTF exposure was processed by the PTF photometric pipeline which included image splitting, de-biasing, flat-fielding, generation of mask images, source extraction, astrometric calibration and photometric calibration (Grillmair et al. 2010, Laher et al. 2014, PASP, submitted). The final products of this pipeline included reduced images, mask images and source catalogs. The absolute photometric calibration, described in Ofek et al. (2012a,b), was done by using SDSS stars (York et al. 2000) and routinely reached a precision of  $\sim 0.02 \text{ mag}$ . In this work, we used source catalogs computed by SEXtractor (Bertin & Arnouts 1996) to extract asteroid lightcurves and employed relative (lightcurve-calibrated) photometry (for algorithm details see Levitan et al. 2011; Ofek et al. 2012a) which typically had a relative photometry accuracy of  $\sim 3 \text{ mmag}$  and  $\sim 0.1 \text{ mag}$  in the bright ( $\sim 15 \text{ mag}$ ) and faint (i.e.,  $\sim 19 \text{ mag}$ ) ends, respectively (Agüeros et al. 2011; Levitan et al. 2011; Ofek et al. 2011). The photometric calibration described above was done on night-, field- and CCD-bases. Therefore, a systemic offset was introduced to each data set obtained from different CCDs, fields and nights. This small offset will be corrected in the period fitting process, later described in Section 3.4.

### 3.2. Light Curve Extraction of Known Asteroids

The detections in a PTF source catalog were divided into stationary sources (i.e., the source would be detected at the same position repeatedly) and non-stationary sources (e.g., moving objects and false detections). To rule out the detections of stationary sources in the following asteroid lightcurve extraction, we performed a spatial cross match with a radius of  $1''$  on each source catalog against the reference source catalog. To build the reference source catalog, we used three PTF source catalogs with the best seeing of each night to pick out the sources that had been detected more than three times in the same position (i.e., within  $1''$  radius). The mean position of the detections of the same reference source was assigned to be its RA and Dec. Then, we performed another spatial cross match with a radius of  $1''$  on the detections of non-stationary sources of each source catalog against the ephemerides of the asteroids with  $V \leq 22$  mag. The asteroidal ephemerides were obtained from MPCChecker<sup>2</sup> according to our exposures. In the last, the detections from the same asteroid were combined to generate its lightcurve. When a lightcurve contained more than five detections, it was identified as a real event (hereafter, the PTF detected asteroids).

### 3.3. Photometric Stability Evaluation

The photometric stability of each source catalog was also evaluated. To do this, we chose the reference sources in the 17–18  $R$  magnitude range that had standard deviations  $\leq 0.075$  mag during the whole campaign (i.e., relatively brighter sources without brightness variations) to be the photometric reference stars (hereafter, photo-ref-stars). Then, we grouped the photo-ref-stars into bins of 0.1 mag and calculate their mean magnitudes and

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<sup>2</sup>the online ephemerides service hosted at the Minor Planet Center; <http://scully.cfa.harvard.edu/cgi-bin/checkmp.cgi>

standard deviations for each source catalog. To judge the photometric stability of each source catalog, we only considered those bins that had more than 30 photo-ref-stars. When a source catalog had one of the following conditions, it would be identified as photometrically unstable and not to be used in the asteroid rotation period analysis: a) three or more bins had mean magnitudes out of the bin boundaries, b) three or more bins had standard deviations  $\geq 0.075$  mag and c) six or more bins had less than 30 photo-ref-stars. In general, most source catalogs (i.e.,  $\sim 90$  %) could fulfill the requirement described above. The rest failing to pass the criteria were mostly due to the bad weather exposures which usually made the three conditions happen at the same time. Fig. 3 shows the number distributions of the photo-ref-stars of  $17.5 < \text{mag} < 17.6$  of all source catalogs for each CCD in field 3655. Most catalogs had more than 80 photo-ref-stars and only several catalogs had less than 30. We also excluded the detections that were flagged by the PTF photometric pipeline as artifacts (e.g., aircraft/satellite track, high dark current pixel, noisy/hot pixel, saturated pixel, dead/bad pixel, ghost image, dirt on the optics, CCD-bleed or bright star halo and the defects flagged by the SExtractor).

### 3.4. Rotation Period Analysis

For measuring the synodic rotation periods of the PTF detected asteroids, the observing times were corrected for light-travel time (i.e., the time interval of photon traveling from object to Earth) and the magnitudes were reduced to both heliocentric ( $r$ ) and geocentric  $\Delta$  distances at 1 AU by

$$M_{R(r=1,\Delta=1)} = R + 5 \log(r\Delta), \quad (1)$$

where  $M_R$  is the  $R$  band reduced magnitude. The orbital elements were obtained from the Minor Planet Center<sup>3</sup> and the heliocentric and geocentric distances were calculated by the PyEphem<sup>4</sup>.

Since the phase angles ( $\alpha$ ) only had a small change in a campaign over four-nights, we applied the  $H$ – $G$  system with a fixed  $G_R$  slope of 0.15 to estimate the absolute magnitude  $H_R$  (Bowell et al. 1989):

$$H_R = \langle M_{R(r=1, \Delta=1)} \rangle + 2.5 \log[(1 - G_R)\phi_1 + G_R\phi_2], \quad (2)$$

where  $\phi_1$  and  $\phi_2$  are the phase angle parameters as below:

$$\phi_1 = \exp[-3.33 \tan(0.5\langle\alpha\rangle)^{0.63}], \quad (3)$$

$$\phi_2 = \exp[-1.87 \tan(0.5\langle\alpha\rangle)^{1.22}]. \quad (4)$$

Then, we fitted a second-order Fourier series to each asteroid lightcurve that had more than eight detections to search the periodicity:

$$M_{i,j} = \sum_{k=1,2}^{N_k} B_k \sin \left[ \frac{2\pi k}{P} (t_j - t_0) \right] + C_k \cos \left[ \frac{2\pi k}{P} (t_j - t_0) \right] + Z_i, \quad (5)$$

where  $M_{i,j}$  is the  $R$  band reduced magnitude measured at the light-travel time corrected epoch  $t_j$ ,  $B_k$  and  $C_k$  are the Fourier coefficients,  $P$  is the rotation period and  $t_0$  is an arbitrary epoch. As described in Section 3.1, the photometric calibration was carried out on night-, field- and CCD-bases. Thus, we also fitted a constant value  $Z_i$  in Eq. (5) to correct the small systematic offsets between different data sets, where a data set was defined as all the measurements taken on the same night, field and CCD with the subscript  $i$  marking the  $i$ th data set. The Eq. (5) was solved by using least-squares minimization

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<sup>3</sup><http://minorplanetcenter.net>

<sup>4</sup><http://rhodesmill.org/pyephem/>



for each given  $P$  to obtain the other free parameters. We tried the 0.25–50 frequency range with a step of 0.0025 to cover the majority of asteroid rotation periods (e.g. about 20 min to about 80 h; Pravec & Harris 2000). Then, we reviewed all possible rotation periods (i.e., the periods with outstanding  $\chi^2$  values from the others) for each objects by inspecting the folded lightcurves to pick out the best result and assigned a quality code  $U$  as introduced by Warner et al. (2009, ; where ‘3’ means highly reliable, ‘2’ means some ambiguity, ‘1’ means possible but may be wrong and ‘0’ means no detection). To estimate the uncertainty of the derived rotation period, we calculated the range of periods with  $\chi^2$  smaller than  $\chi_{best}^2 + \Delta\chi^2$ , where  $\chi_{best}^2$  is the  $\chi^2$  of the pick out period and  $\Delta\chi^2$  is calculated from the inverse  $\chi^2$  distribution assuming  $1 + 2N_k + N_s$  degrees of freedom. The amplitudes of the objects with full lightcurve coverage were adopted from the second-order Fourier series fitting. However, this would probably underestimate the amplitudes of the lightcurves of sharp minimum/maximum. Some folded lightcurves just covered part of a rotation period and some only showed a single minimum due to their sparse data points, however, we still assigned them  $U = 2$  for their clear folded lightcurves. To give lower limits on the amplitude for these objects, we calculated a 90% magnitude range centered on the range median of their small offset corrected lightcurves. This can reject the upper and lower 5% detections to avoid those outliers (i.e., the detections obviously deviated from the expected maximum/minimum of the folded lightcurve). Such outliers could be the detections contaminated by the nearby bright stars or the artifacts not filtered out from the lightcurve extraction. These objects need followup observations to confirm their rotation periods. We will have more discussion of these cases in Section 4.2. To have an overview on our data analysis procedure, we show the flow chart in Fig. 2.

## 4. Results

### 4.1. Detected asteroids

There were 2500 PTF detected asteroids in a magnitude range of 14–22 mag in this work (see Fig. 4) and their distributions of the semimajor axes ( $a$ ), eccentricities ( $e$ ), inclinations ( $i$ ) and absolute magnitudes ( $H_R$ ) along with that of all known asteroids with  $a < 6$  AU are shown in Fig. 5. The majority of the PTF detected asteroids were main belt asteroids and the others were a few Hilda, Jovian Trojan asteroids and near Earth objects. The PTF detection rate is higher for the inner main belt asteroids and fair to all eccentricities. Since we focused on the ecliptic plane, most PTF detected asteroids concentrate on low inclinations.

The diameters of the PTF detected asteroids were obtained from the preliminary results of *WISE*/NEOWISE (Grav et al. 2011; Mainzer et al. 2011; Masiero et al. 2011). While the *WISE*/NEOWISE diameters were not yet available, the diameters were estimated by the following equation

$$D = \frac{1130}{\sqrt{p_R}} 10^{-H_R/5}, \quad (6)$$

where  $D$  is the diameter in units of km,  $p_R$  is the geometric albedo in  $R$  band and the conversion constant, 1130, is adopted from Jewitt et al. (2013). According to the semimajor axis ranges, we used three empirical values for geometric albedo, which are (a)  $p = 0.20$  for  $a \leq 2.5$  AU, (b)  $p = 0.08$  for  $2.5 < a \leq 2.8$  AU and (c)  $p = 0.04$  for  $a > 2.8$  AU (Tedesco et al. 2005). The plot of the semimajor axis vs. diameter for the PTF detected asteroids is given in Fig. 6, which shows the PTF was able to detect a few hundred meters size objects in inner main belt, kilometer size objects in the outer main belt and 10 kilometer size objects for Hilda/Jovian Trojan asteroids.

## 4.2. Derived Rotation Periods

Among the 2500 PTF detected asteroids, 313 objects had rotation periods with  $U \geq 2$  (hereafter, the PTF-U2 asteroids). The information of the PTF-U2 asteroids are summarized in Table 2 and their folded lightcurves are presented in Figs. 7–16. 18 PTF-U2 asteroids have published rotation periods in the Asteroid Light Curve Database (LCDB; Warner et al. 2009)<sup>5</sup>, and 16 of them show good agreements on their rotation periods that indicated that our result were highly reliable. The possible reasons that the rotation periods of the other two asteroids, (182) Elsa and (16541) 1991 PW18, showed discrepancies between this work and the LCDB are discussed below.

Compared to the published rotation period of  $> 9$  hours with  $U = 1$  for 1991 PW18 (Warner et al. 2009), ours is 7.0 hours with  $U = 2$  which showed a clear folded lightcurve, therefore, we believe our result to be more accurate.

The rotation period of (182) Elsa, a relatively large asteroid ( $\sim 40$  km), had been carefully studied by Pilcher et al. (2009) with an intensively observed lightcurve. They gave a rotation period of 80.088 hours and a clear folded lightcurve that showed similar primary and secondary minimums. Since our data set only covered part of its rotation period, the fitting procedure misidentifies a rotation period of 15.97 hours (i.e.,  $\sim 1/5$  of the published result) and gives a clear folded lightcurve. As per the criteria described in Section 3.4, we still assigned  $U = 2$  to our rotation period.

From the case of (182) Elsa, we notice that when a folded lightcurve only covered part of a rotation period, our fitting procedure was possible to lead us to an inaccurate rotation period. In 312 PTF-U2 asteroids, we found 20 objects faced this situation and five more showed folded lightcurves with a single minimum. Since these 25 objects possibly had

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<sup>5</sup><http://www.minorplanet.info/lightcurvedatabase.html>

relatively large uncertainties in their rotation periods, we exclude them in the following statistical analysis. The folded lightcurves of these 25 objects are presented in Fig. 15 and 16, respectively.

There were 49 PTF detected asteroids with  $R < 18$  mag and more than 20 detections which do not have rotation period determinations (see Table 3). Since the small offset corrections for the most PTF-U2 asteroids (i.e.,  $> 90\%$ ) are of  $R < 0.1$  mag and the relative photometry accuracy of  $R = 18$  mag is  $\sim 0.05$  mag, it was unlikely to detect a lightcurve variation of  $R < 0.1$  mag in our analysis and this has also been seen in Fig. 18. Among 49 objects, only 5 belonged to this case. The other 44 objects with lightcurve variations of  $R > 0.1$  mag should have had a rotation period determination. However, most of these objects showed segmented lightcurves with a long trend over our four-night observation time span (i.e., the lightcurve coverage was very limited). This indicates that these objects might have relatively long rotation periods (i.e., several days) and would have less chance to have rotation period determinations from our four-night observation. In addition, 18 out of these 44 objects had diameters of  $> 10$  km and 6 of them (i.e.,  $\sim 33\%$ ) have lightcurve variations of  $R > 0.3$  mag. Comparing to the rest 26 objects, in which 10 objects ( $\sim 38\%$ ) have lightcurve variations of  $R > 0.3$  mag, both groups showed similar fractions for lightcurve variation. However, this result was based on the lower limit of the lightcurve amplitude (i.e., we only had partial lightcurve coverage) and should be verified when their full lightcurves are available.

### 4.3. Statistical Analysis

The asteroid spin rate limit is one of the particular interesting subjects. Fig. 17 shows the plot of the diameter vs. rotation period for the PTF-U2 asteroids and the objects adopted from the Asteroid Light Curve Database with  $U \geq 2$ . The PTF-U2 asteroids

occupy the dense region of the plot. Because our observation was insensitive to detect a long rotation period, the PTF-U2 asteroids showed a lack of slow rotators. The “spin barrier” at  $\sim 2.2$  hours can clearly be seen for asteroids with diameters larger than a few hundred meters, which indicated the spin rate limit for gravitationally bound aggregations (i.e., “rubble pile”). Several super-fast-rotators (i.e., rotation period  $< 2.2$  hours) located at the upper-left corner, which were usually small sized objects and could be of a monolithic nature (Pravec & Harris 2000). The “spin barrier” can also be seen on Fig. 18, which shows the plot of the spin rate vs. lightcurve amplitude along with the spin rate limits for “rubble pile” asteroids with bulk densities of 3, 2 and 1 g/cm<sup>3</sup> adopted from Pravec & Harris (2000). One unusual object, (167714) 2001 OE84, which has a diameter of  $\sim 600$  m and a rotation period of  $\sim 0.3$  hours faster than the “spin barrier”, and Pravec et al. (2002) treated this object as an exceptional case. However, Holsapple (2007) introduced a size-dependent strength asteroid model, which included tensile and cohesiveness in addition to gravity, to explain the existence of kilometer size super-fast-rotators. In this study, we detected one super-fast-rotator candidate, (49719) 1999 VE50, which has a rotation period of 1.24 hours, an amplitude of  $\sim 0.29$  mag and a diameter of  $\sim 2.6$  km. However, as pointed out by Harris et al. (2012), this could be a result of a random combination of scattered data points showing relatively small lightcurve amplitude. Therefore, to confirm such fast spin rate of 1999 VE50 requires a followup observation and a detailed investigations.

The small plot at the upper right corner of Fig. 17 is the detailed view of the dense region, on which we also plot the geometric mean spin rate of the PTF-U2 asteroids and that of the LCDB by using a running box containing 30 and 100 objects, respectively. Both geometric mean spin rates begin with a flat and then start to decrease at  $D \sim 10$  km. The decrease at  $D \sim 10$  km was considered as a consequence of the transition from the “small” asteroids, which showed a non-Maxwellian spin rate distribution with an excess of both fast and slow rotators, to the “large” asteroids, which showed a Maxwellian

spin rate distribution (Pravec et al. 2002). Several studies indicated the “large” asteroid begins at the 30–50 km diameter range (Fulchignoni et al. 1995; Donnison & Wiper 1999; Pravec & Harris 2000), but we were not able to determine where the “large” asteroids begins due to only a few objects with  $D > 30$  km in the PTF-U2 asteroids.

The spin rate distribution of the “small” asteroids also provided valuable information to understand asteroid spin rate evolution. In order to compare with the result of Pravec et al. (2008, P08 hereafter), we selected asteroids with  $3 \text{ km} < D \leq 15 \text{ km}$  from the PTF-U2 asteroids, (Masiero et al. 2009, M09 hereafter) and the LCDB to generate spin rate distributions in Fig. 19. In contrast to the flat distribution of P08, the other three showed a number decrease at the spin rate of  $> 5$  rev/day. Warner et al. (2009) pointed out the number decrease was an observational bias due to a tendency toward smaller lightcurve amplitude with increasing spin rates (see Fig. 18), while M09 showed the multiple YORP-braking stages that existed in main belt asteroids could lead to such a result. However, M09 also mentioned that the discrepancy between P08 and the others could be the result of different survey methods (i.e., the PTF, M09 and the LCDB are untargeted surveys or collecting data set while P08 targets individual asteroids with  $a < 2.5$  AU). If we restrict the comparison to the asteroids with  $a < 2.5$  AU, regardless of only two samples in M09, the number decrease at the spin rate of  $> 5$  rev/day still showed on the PTF-U2 asteroids and the LCDB (see the dashed lines in Fig. 19). Therefore, a large sample of asteroid rotation period from a single survey like the PTF is of paramount importance to reveal the spin rate distribution of the “small” asteroids. The best-fit Maxwellian distribution for the PTF-U2 asteroids is also shown on Fig. 19. We see the PTF-U2 asteroids deviate somewhat to the Maxwellian form, which means that mechanisms, other than collision, involved in asteroid spin rate evolution as well.

To gain an approximate idea of how the spin rate distributes for different taxonomic

type asteroids, we summarized the plots of the diameter vs. rotation period and the distributions of spin rate for available S-, C- and V-type asteroids in Fig. 20. The taxonomic types were determined by using SDSS color (Parker et al. 2008). We were not able to tell the difference between the scatter plots from one another by eyes (the left column in Fig. 20), however, the spin rate distributions showed some difference (the right column in Fig. 20). The C-type’s distribution showed a decreasing number with increasing spin rate, the S-type’s distribution had a number drop at spin rate of  $> 5$  rev/day and the V-type’s distribution demonstrated a number enhancement around spin rate of 6–5 rev/day. Moreover, none of them could be fitted reasonably by a Maxwellian distribution. When we ran the two-sample Kolmogorov-Smirnov (KS) test for each pair of these three type asteroids to compare their spin rate distributions, all the KS test  $p$ -values were much lower than 0.005. Although this indicates these three different types were unlikely to come from the same population, we believed it could be greatly affected by insufficient number and incompleteness in our samples, especially the different diameter ranges of these three subgroups (see the left column in Fig. 20). Therefore, we expect to have a more accurate comparison on this topic when more asteroid rotation periods are available from observations now in planning.

The asteroid lightcurve profile is a powerful tool to probe asteroid shape as well as to discover binary asteroid. The inset of Fig. 18 shows the plot of the diameter vs. lightcurve amplitude. Both the PTF-U2 asteroids and the LDCB show a boundary from the upper-middle to the lower-right that indicates relatively large asteroids tend to have small lightcurve amplitudes. Most PTF-U2 asteroids show simple sinusoidal-like folded lightcurves. However, we found two binary asteroid candidates, (7452) Izabelyuria and (75640) 2000 AE55 (see Fig. 15), whose lightcurves showed a deep V-shape minima and an inverse U-shape maxima with a relatively long rotation period (Pravec et al. 2006). The fractions of binary asteroid in different asteroid groups provide important constraints

on the binary asteroid formation models. Therefore, an overall survey on asteroid binary population with large samples could reveal a clearer picture on how different mechanisms work on binary asteroid formation.

## 5. Summary and Discussion

This study has demonstrated the capability of the PTF to pursue large amount of asteroid rotation periods via a 12-PTF-fields survey in a four consecutive nights observation with a cadence of  $\sim 20$  min during February 15–18, 2013. The PTF photometric data were used to extract the lightcurves of known asteroids and measure their rotation periods. There were 2500 known asteroids with more than five detections and 312 of them had highly reliable rotation periods in this work. The plots of the spin rate vs. diameter for the PTF-U2 asteroids and the LCDB were very similar. Both show the “spin barrier” clearly at  $\sim 2.2$  hours and similar geometric mean spin rates. The spin rate distribution of the PTF-U2 asteroids showed a number decrease at the spin rate of  $> 5$  rev/day, which is not a Maxwellian distribution nor as flat as shown by Pravec et al. (2008). The non-Maxwellian distribution indicated that the asteroid spin rate evolution was not only affected by collision, but also by other mechanics, in particular the YORP effect. The rough test for available S-, C- and V-type asteroids does not have a clear conclusion on any difference between the spin rate distributions of various taxonomic types. However, we did find one super-fast-rotator candidate, (49719) 1999 VE50, which had a rotation period of 1.24 hours and a diameter of  $\sim 2.6$  km. If the fast spin rate of 1999 VE50 is confirmed, the size-dependent strength asteroid model will be supported. In addition, we also detected two binary asteroid candidates, (7452) Izabelyuria and (75640) 2000 AE55. The tendency toward smaller lightcurve amplitudes with increasing diameter is seen in the PTF-U2 asteroids as well, which means large asteroids tend to have rounder shapes.



Since our target fields are close to the Galactic plane toward the anti-Galactic center direction, the detection rate of known asteroids is expected to be lower than that in the off-Galactic plane fields, and so does the amount of highly reliable rotation period. For an approximate estimation, it is very likely to obtain 10000 asteroid rotation periods by reproducing this kind of observation around 20–30 times. In addition, we also expect to retrieve more asteroid rotation periods from previously observed high cadence fields, which is now under analysis. Such a huge amount of asteroid rotation periods can provide more definite constraints on various studies, such as how different mechanisms (e.g., collision, YORP effect and tidal force during their encounter with planets) involve in asteroid spin rate evolution, how tensile and cohesiveness account for the spin rate limits of different size asteroids (i.e., the size-dependent strength for asteroids; Holsapple 2007) and the censor on asteroid lightcurve profile (i.e., asteroid shape/axis ratio). We also can further investigate the asteroid spin rate as a function of the size, taxonomy, dynamical group and asteroid family. In addition, more binary asteroids will be discovered to reveal their fractions in different asteroid populations and provide important constraints on their formation models.

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Table 1. The observation information.

Field ID	RA	Dec.	$[l, b]$	Feb 15	Feb 16	Feb 17	Feb 18
	( $^{\circ}$ )	( $^{\circ}$ )	( $^{\circ}$ )	$\Delta t, N_{\text{exp}}$	$\Delta t, N_{\text{exp}}$	$\Delta t, N_{\text{exp}}$	$\Delta t, N_{\text{exp}}$
3654	101.02	21.38	[192.97, 8.02]	3.4, 10	5.1, 16	6.8, 19	6.4, 19
3655	104.69	21.38	[194.47, 11.11]	3.4, 10	5.3, 15	6.8, 19	6.4, 19
3656	108.37	21.38	[195.92, 14.23]	3.4, 10	5.3, 15	7.2, 20	6.7, 20
3657	112.04	21.38	[197.33, 17.36]	3.4, 10	5.4, 15	7.2, 20	7.1, 21
3658	115.71	21.38	[198.72, 20.52]	3.4, 10	5.5, 16	7.6, 21	7.4, 22
3749	90.93	23.62	[186.63, 0.81]	3.4, 10	5.3, 14	6.4, 18	6.0, 18
3750	94.64	23.62	[188.27, 3.79]	3.4, 10	5.1, 15	6.4, 18	6.0, 18
3751	98.35	23.62	[189.84, 6.81]	3.4, 10	5.1, 15	6.8, 19	6.4, 19
3752	102.06	23.62	[191.34, 9.87]	3.4, 10	5.0, 14	6.8, 19	6.7, 20
3753	105.77	23.62	[192.80, 12.95]	3.4, 10	5.1, 15	7.2, 20	6.7, 20
3754	109.48	23.62	[194.21, 16.07]	3.4, 10	5.1, 15	7.6, 21	7.1, 21
3755	113.20	23.62	[195.58, 19.21]	3.4, 10	5.4, 15	7.6, 21	7.4, 22

Note. —  $\Delta t$  is the time duration spanned by each observing set in hours and  $N_{\text{exp}}$  is the total number of exposures for each night and field.

Table 2. Synodic rotation periods of 313 asteroids with  $U \geq 2$ .

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
00182* <sup>†</sup>	(182) Elsa	2.42	0.19	2.00	107.2	310.2	K13B4	44.0 <sup>w</sup>	2.18	1.32	16.50	9.07±0.33	4	84	12.38±0.00	15.97±0.31	0.34	2
00300*	(300) Geraldina	3.21	0.06	0.73	42.7	327.1	K134I	72.7 <sup>w</sup>	3.23	2.52	13.82	9.51±0.09	4	57	14.85±0.00	6.86±0.02	0.16	3
00543*	(543) Charlotte	3.06	0.16	8.48	295.0	109.8	K134I	45.6 <sup>w</sup>	2.87	2.06	13.24	9.23±0.09	4	61	13.85±0.00	10.69±0.05	0.20	3
00662* <sup>†</sup>	(662) Newtonia	2.55	0.22	4.12	133.7	165.7	K134I	22.4 <sup>w</sup>	3.11	2.29	12.05	10.00±0.15	4	47	15.06±0.00	20.60±0.18	0.42	2
00758* <sup>†</sup>	(758) Mancunia	3.19	0.15	5.61	106.2	315.2	K134I	85.0 <sup>w</sup>	2.87	2.09	14.07	8.11±0.16	4	62	12.85±0.00	12.77±0.05	0.26	2
01350*	(1350) Rosselia	2.86	0.09	2.94	139.6	238.5	K134I	21.1 <sup>w</sup>	2.86	2.12	15.20	10.36±0.25	4	59	14.99±0.00	8.16±0.01	0.52	3
01633*	(1633) Chimay	3.19	0.12	2.68	114.1	65.0	K134I	37.7 <sup>w</sup>	2.96	2.16	13.19	10.36±0.17	4	55	15.21±0.00	6.58±0.01	0.34	3
01778	(1778) Alfven	3.15	0.13	2.47	106.2	135.8	K134I	20.6 <sup>w</sup>	3.33	2.51	11.15	11.59±0.15	4	55	16.88±0.01	4.82±0.00	0.37	3
01913	(1913) Sekanina	2.88	0.08	1.57	358.5	35.2	K134I	13.4 <sup>w</sup>	2.86	2.01	12.35	11.64±0.15	4	56	16.16±0.01	13.97±0.06	0.27	3
01955*	(1955) McMath	2.85	0.07	1.01	258.2	154.7	K134I	9.8 <sup>w</sup>	2.75	2.05	16.84	11.97±0.15	4	59	16.64±0.01	5.57±0.00	0.39	3
02054*	(2054) Gawain	2.96	0.10	3.79	293.3	183.6	K134I	18.0 <sup>w</sup>	2.67	1.97	17.60	12.53±0.34	4	44	17.01±0.01	11.46±0.04	1.04	2
02217*	(2217) Eltigen	3.16	0.17	2.25	127.5	173.6	K134I	31.7 <sup>w</sup>	3.67	2.91	11.09	11.22±0.12	4	53	17.07±0.02	6.89±0.02	0.30	2
02270*	(2270) Yazhi	3.15	0.14	2.12	76.0	188.8	K134I	26.7 <sup>w</sup>	3.52	2.78	12.06	11.26±0.15	3	40	16.96±0.01	7.75±0.04	0.35	2
02316	(2316) Jo-Ann	2.45	0.17	1.82	148.7	147.6	K134I	13.1 <sup>w</sup>	2.85	2.00	11.94	12.64±0.11	4	47	17.12±0.01	32.88±1.30	0.31	2
02344 <sup>†</sup>	(2344) Xizang	2.75	0.19	3.90	99.3	239.9	K134I	16.3 <sup>w</sup>	3.11	2.30	12.27	11.54±0.14	1	20	16.58±0.01	13.03±1.50	0.36	2
02627	(2627) Churyumov	3.11	0.18	2.50	109.6	314.8	K134I	19.7 <sup>w</sup>	2.71	1.95	15.93	12.09±0.29	4	58	16.61±0.01	7.66±0.01	0.70	3
02762*	(2762) Fowler	2.33	0.15	4.71	304.1	186.2	K134I	4.5 <sup>w</sup>	1.98	1.18	21.95	12.64±0.23	2	25	15.55±0.00	5.23±0.10	0.52	2
02804	(2804) Yrjo	3.01	0.08	11.23	109.2	174.4	K13B4	18.6 <sup>w</sup>	3.24	2.50	13.31	11.15±0.16	4	79	16.49±0.01	8.12±0.01	0.25	3
02811	(2811) Stremchovi	2.86	0.04	1.03	331.9	107.4	K13B4	12.3 <sup>w</sup>	2.79	1.95	12.82	11.59±0.15	4	73	16.01±0.00	3.25±0.00	0.32	3
03413	(3413) Andriana	2.25	0.13	5.80	307.0	288.0	K134I	6.0 <sup>w</sup>	2.35	1.58	18.38	13.13±0.12	4	47	16.92±0.01	11.18±0.09	0.10	2
03559	(3559) Violaumayer	2.48	0.22	3.82	314.2	71.0	K134I	10.2 <sup>w</sup>	2.41	1.61	16.96	13.95±0.12	3	34	17.81±0.02	3.79±0.01	0.18	2
03615 <sup>†</sup>	(3615) Safronov	3.16	0.13	2.11	134.9	111.8	K134I	26.2 <sup>w</sup>	3.34	2.47	9.39	11.44±0.15	4	55	17.11±0.01	22.70±0.32	0.18	2
03640*	(3640) Gostin	2.22	0.09	4.31	289.3	155.2	K134I	7.6 <sup>w</sup>	2.07	1.25	19.94	12.26±0.14	4	58	15.33±0.00	3.26±0.00	0.35	3
04014	(4014) Heizman	3.42	0.03	1.11	270.7	110.4	K134I	20.4	3.44	2.58	9.52	12.21±0.11	4	55	17.58±0.02	9.36±0.07	0.15	2

Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
04049	(4049) Noragal'	3.08	0.27	2.38	97.3	217.6	K134I	19.5 <sup>w</sup>	3.71	3.09	13.03	12.26±0.15	4	46	18.33±0.04	9.16±0.13	0.32	3
04242	(4242) Brecher	3.12	0.15	0.28	29.3	211.2	K134I	14.1 <sup>w</sup>	3.41	2.78	14.14	12.95±0.32	4	33	18.60±0.05	7.68±0.02	0.75	3
04334	(4334) Foo	3.14	0.20	1.63	61.8	349.1	K134I	14.2	2.80	2.02	14.50	13.00±0.15	4	56	17.58±0.02	7.42±0.03	0.17	2
04365	(4365) Ivanova	2.85	0.05	1.04	244.7	57.2	K134I	7.4 <sup>w</sup>	3.00	2.36	16.30	12.60±0.27	4	47	17.70±0.03	9.84±0.02	0.69	3
04385	(4385) Elsasser	3.17	0.18	0.58	61.1	311.4	K13B4	10.8 <sup>w</sup>	3.14	2.44	14.54	12.90±0.19	3	84	18.13±0.02	5.57±0.01	0.58	3
04611*	(4611) Vulkaneifel	2.61	0.19	13.78	116.3	274.0	K134I	11.3 <sup>w</sup>	2.46	1.74	18.87	11.64±0.32	3	36	15.83±0.00	3.75±0.00	0.49	3
04796*	(4796) Lewis	2.35	0.18	2.27	296.5	35.7	K134I	5.0	2.72	1.85	12.00	13.52±0.20	4	49	17.71±0.02	3.51±0.01	0.49	3
04927	(4927) O'Connell	2.89	0.09	1.16	329.1	41.4	K13B4	7.0 <sup>w</sup>	2.90	2.23	16.38	13.13±0.13	4	105	18.04±0.02	9.78±0.06	0.09	2
05673	(5673) McAllister	2.34	0.06	1.60	338.5	336.2	K13B4	5.3 <sup>w</sup>	2.49	1.64	14.58	13.34±0.21	4	64	17.24±0.01	5.81±0.00	0.56	3
05770	(5770) 1987 RY	3.21	0.18	0.38	63.1	251.4	K134I	14.3 <sup>w</sup>	3.75	2.94	9.81	12.86±0.26	4	54	18.67±0.04	13.91±0.06	0.46	2
05823	(5823) Oryo	2.77	0.16	7.97	308.6	88.7	K134I	8.7 <sup>w</sup>	2.65	1.83	14.32	12.44±0.23	4	51	16.63±0.01	2.79±0.00	0.43	2
05891	(5891) Gehrig	2.43	0.13	3.34	300.5	110.5	K13B4	5.3 <sup>w</sup>	2.31	1.44	14.59	13.17±0.27	4	65	16.60±0.01	3.57±0.00	0.74	3
05894	(5894) Telc	2.19	0.09	5.17	313.5	279.1	K13B4	6.0 <sup>w</sup>	2.25	1.44	18.37	13.03±0.24	4	60	16.60±0.01	17.65±0.03	0.63	3
05941	(5941) Valencia	2.89	0.06	1.30	217.1	192.3	K134I	13.6	2.80	2.05	15.32	13.10±0.33	3	34	17.91±0.03	10.16±0.04	1.18	2
06102	(6102) Visby	2.60	0.16	1.76	310.8	358.7	K134I	4.5 <sup>w</sup>	3.02	2.19	12.17	13.76±0.18	4	47	18.60±0.03	3.28±0.01	0.28	3
06221	(6221) Ducentesima	3.18	0.10	1.80	146.6	66.6	K134I	13.2 <sup>w</sup>	3.18	2.39	12.35	12.96±0.20	4	46	18.08±0.02	13.66±0.10	0.34	2
06537	(6537) Adamovich	2.18	0.20	4.03	120.1	200.6	K134I	4.3 <sup>w</sup>	2.58	1.72	12.97	13.81±0.14	4	50	17.79±0.02	2.43±0.01	0.12	2
06568 <sup>†</sup>	(6568) Serendip	2.54	0.17	8.45	308.5	105.4	K13B4	9.0 <sup>w</sup>	2.34	1.49	15.41	14.04±0.17	4	69	17.56±0.02	12.00±0.09	0.39	2
06753	(6753) Fursenko	2.25	0.14	3.00	300.1	352.5	K134I	5.6	2.56	1.74	15.10	13.26±0.20	4	48	17.27±0.01	4.99±0.03	0.19	2
06932	(6932) Tanigawadake	2.33	0.25	3.72	113.9	181.3	K134I	5.2 <sup>w</sup>	2.90	2.05	11.77	13.71±0.16	4	42	18.28±0.03	3.79±0.00	0.45	3
06944	(6944) 1979 MR3	2.32	0.14	7.66	122.3	174.8	K134I	3.4 <sup>w</sup>	2.63	1.78	13.04	14.14±0.15	4	39	18.23±0.03	3.09±0.05	0.19	2
07195	(7195) Danboice	2.42	0.23	9.06	125.3	219.6	K134I	5.5 <sup>w</sup>	2.79	1.92	11.63	13.38±0.13	4	50	17.71±0.02	8.67±0.06	0.18	2
07244 <sup>✓</sup>	(7244) Villa-Lobos	2.87	0.08	2.61	148.6	186.3	K134I	7.5 <sup>w</sup>	3.05	2.27	13.26	12.85±0.21	4	42	17.85±0.02	16.00±0.44	0.54	2
07380	(7380) 1981 RF	2.43	0.19	3.42	117.9	239.0	K134I	9.1 <sup>w</sup>	2.61	1.81	15.30	14.11±0.20	4	53	18.29±0.03	4.37±0.00	0.46	3

Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
07452 <sup>†b</sup>	(7452) Izabelyuria	3.11	0.20	2.74	118.1	257.7	K134I	10.1 <sup>w</sup>	3.03	2.34	15.20	13.34±0.37	4	50	18.67±0.04	11.79±0.06	0.75	2
07458	(7458) 1984 DE1	3.73	0.17	1.77	323.6	238.9	K134I	25.2	3.62	2.89	11.67	11.75±0.13	4	53	17.54±0.02	16.70±0.15	0.34	2
07747	(7747) Michalowski	2.29	0.27	5.05	289.4	28.6	K134I	4.5 <sup>w</sup>	2.81	2.11	16.55	13.74±0.27	4	38	18.39±0.03	4.50±0.01	0.42	2
07751	(7751) 1988 UA	2.47	0.19	1.09	256.5	92.7	K134I	4.2 <sup>w</sup>	2.73	1.91	14.08	14.96±0.30	4	42	19.43±0.07	9.36±0.07	0.73	3
07980	(7980) Senkevich	2.82	0.08	1.64	2.7	358.8	K134I	4.3 <sup>w</sup>	2.91	2.10	13.19	13.51±0.20	4	56	18.23±0.03	10.48±0.07	0.37	2
07998	(7998) Gonczi	2.35	0.12	5.58	108.6	137.1	K13B4	3.8	2.48	1.66	15.58	14.14±0.33	4	50	18.01±0.02	6.50±0.02	0.66	3
08080	(8080) Intel	2.86	0.29	9.43	306.3	60.1	K134I	6.6 <sup>w</sup>	2.94	2.14	13.23	12.93±0.14	4	45	17.71±0.02	3.54±0.01	0.27	3
08102	(8102) Yoshikazu	2.83	0.03	3.26	108.9	328.4	K13B4	5.4 <sup>w</sup>	2.77	1.96	13.88	13.46±0.16	4	68	17.91±0.02	3.34±0.01	0.29	2
08245	(8245) Molnar	2.41	0.14	1.46	319.0	256.8	K134I	3.6 <sup>w</sup>	2.40	1.60	17.09	14.41±0.21	4	48	18.25±0.03	4.72±0.02	0.36	2
08859	(8859) 1991 PQ11	2.53	0.09	5.24	307.9	31.3	K134I	6.0 <sup>w</sup>	2.68	1.92	15.99	13.26±0.27	4	50	17.69±0.02	3.90±0.00	0.62	3
08910	(8910) 1995 WV42	3.12	0.24	14.83	108.1	235.1	K134I	13.3 <sup>w</sup>	3.45	2.73	12.70	12.88±0.23	4	43	18.41±0.03	10.56±0.03	0.43	2
08976	(8976) Leucura	3.09	0.15	2.10	111.4	341.0	K134I	12.7 <sup>w</sup>	2.66	1.95	17.40	13.43±0.12	4	56	17.89±0.02	5.54±0.01	0.29	3
09196	(9196) Sukagawa	2.21	0.07	3.44	104.4	145.8	K134I	4.7 <sup>w</sup>	2.32	1.63	20.99	13.58±0.41	4	41	17.50±0.02	7.10±0.02	0.87	3
09234	(9234) Matsumototaku	2.20	0.10	2.18	90.1	195.1	K134I	3.3 <sup>w</sup>	2.41	1.58	15.86	14.36±0.36	4	40	18.11±0.03	6.05±0.01	0.86	3
10104	(10104) Hoburgsgubben	2.33	0.08	2.61	317.7	291.8	K134I	4.3 <sup>w</sup>	2.44	1.67	17.59	15.93±0.34	4	33	19.95±0.11	9.40±0.10	0.77	2
10339	(10339) 1991 RK17	2.54	0.10	0.87	232.8	205.2	K134I	4.9 <sup>w</sup>	2.34	1.54	17.68	13.92±0.21	4	36	17.65±0.02	7.90±0.03	0.59	3
10632	(10632) 1998 CV1	3.93	0.20	8.40	111.2	294.9	K134I	22.1	3.47	2.75	12.53	12.04±0.16	4	47	17.65±0.02	9.13±0.06	0.37	2
10762	(10762) von Laue	3.03	0.10	1.44	227.2	158.6	K134I	6.7 <sup>w</sup>	3.03	2.21	12.29	13.33±0.12	4	48	18.20±0.03	4.71±0.01	0.20	3
10947	(10947) Kaiserstuhl	2.37	0.18	4.96	320.2	269.6	K134I	2.8 <sup>w</sup>	2.42	1.59	15.77	14.43±0.11	4	45	18.23±0.03	3.15±0.01	0.19	2
11094	(11094) Cuba	3.07	0.20	2.17	260.9	33.2	K134I	9.9 <sup>w</sup>	3.67	2.90	10.82	13.42±0.18	4	43	19.28±0.06	9.98±0.09	0.42	2
11219	(11219) Benbohn	2.36	0.15	0.63	17.6	190.1	K13B4	3.4 <sup>w</sup>	2.26	1.38	14.70	14.53±0.12	4	62	17.79±0.02	2.57±0.00	0.22	2
11515	(11515) Oshijyo	3.15	0.09	7.88	110.9	307.1	K134I	9.7 <sup>w</sup>	3.01	2.17	11.83	12.38±0.16	4	50	17.13±0.01	3.34±0.01	0.38	3
11776	(11776) Milstein	3.17	0.18	0.45	284.5	75.0	K134I	11.0 <sup>w</sup>	3.29	2.57	13.38	13.82±0.26	4	43	19.18±0.06	3.82±0.02	0.53	2
11946	(11946) Bayle	3.15	0.15	0.52	174.2	79.6	K134I	14.2 <sup>w</sup>	3.43	2.62	10.70	13.16±0.25	4	43	18.56±0.03	14.04±0.24	0.58	2

Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
12834 <sup>†</sup>	(12834) Bomben	2.18	0.15	4.06	129.0	189.6	K134I	3.1 <sup>w</sup>	2.50	1.65	14.30	14.95±0.23	4	40	18.84±0.04	12.20±0.27	0.59	2
12878	(12878) Erneschiller	2.62	0.10	3.64	94.5	244.6	K134I	3.8 <sup>w</sup>	2.81	2.01	14.08	14.24±0.27	3	28	18.76±0.04	4.74±0.01	0.66	2
13188	(13188) Okinawa	2.19	0.09	1.91	334.8	224.8	K134I	2.5 <sup>w</sup>	2.14	1.34	19.63	15.02±0.16	4	47	18.24±0.03	11.75±0.17	0.27	2
13430	(13430) 1999 VM36	2.62	0.25	1.25	228.0	135.8	K134I	6.2 <sup>w</sup>	2.73	1.95	15.01	14.94±0.51	4	32	19.41±0.09	8.09±0.08	1.00	3
13480	(13480) Potapov	2.23	0.22	5.30	309.4	31.2	K134I	2.7	2.56	1.73	14.64	14.84±0.26	4	50	18.89±0.05	10.86±0.07	0.52	2
13919	(13919) 1984 SO4	2.28	0.12	4.98	286.4	55.2	K134I	4.5 <sup>w</sup>	2.43	1.75	20.20	13.56±0.34	4	42	17.56±0.02	6.02±0.02	0.69	2
14196*	(14196) 1998 XH59	2.26	0.22	7.29	114.2	186.3	K134I	4.5 <sup>w</sup>	2.76	1.91	12.46	13.37±0.10	4	38	17.70±0.01	3.24±0.00	0.20	3
14430	(14430) 1992 CH	2.63	0.11	12.62	311.6	168.1	K13B4	6.5 <sup>w</sup>	2.34	1.49	15.39	13.10±0.12	4	59	16.68±0.01	4.84±0.01	0.31	2
14832	(14832) Alechinsky	2.29	0.12	5.73	307.5	77.7	K134I	4.4 <sup>w</sup>	2.28	1.49	18.92	14.02±0.84	4	39	17.71±0.03	8.07±0.02	1.02	2
15277	(15277) 1991 PC7	2.87	0.07	3.22	100.2	230.6	K134I	10.5	3.05	2.25	12.83	13.65±0.18	4	38	18.60±0.04	2.75±0.01	0.28	2
15474	(15474) 1999 BG11	2.85	0.12	1.45	2.9	38.8	K134I	8.2	2.74	1.95	14.64	14.19±0.18	4	53	18.65±0.04	3.53±0.01	0.37	3
15734	(15734) 1990 WV1	2.35	0.04	5.28	131.6	2.0	K134I	2.4 <sup>w</sup>	2.24	1.35	13.90	14.78±0.28	4	50	17.99±0.02	17.20±0.48	0.53	3
16021	(16021) Caseyvaughn	2.33	0.06	5.82	298.1	216.0	K134I	2.6 <sup>w</sup>	2.21	1.36	16.43	14.30±0.09	4	53	17.60±0.02	13.01±0.44	0.20	2
16541*	(16541) 1991 PW18	2.90	0.06	1.73	202.9	206.6	K134I	15.9	2.81	2.07	15.54	12.76±0.19	4	49	17.43±0.02	7.01±0.02	0.47	2
16655	(16655) 1993 TS33	2.39	0.12	4.33	116.8	312.7	K134I	2.7 <sup>w</sup>	2.22	1.35	15.55	14.83±0.09	4	59	18.07±0.02	3.12±0.01	0.11	2
17690 <sup>†</sup>	(17690) 1997 CY2	3.11	0.19	3.77	120.4	1.8	K134I	9.8 <sup>w</sup>	2.52	1.82	18.58	14.02±0.17	4	46	18.13±0.03	11.87±0.06	0.50	2
17848	(17848) 1998 HR133	3.09	0.15	6.02	100.5	199.4	K134I	9.1 <sup>w</sup>	3.54	2.78	11.74	13.89±0.21	4	44	19.54±0.07	6.94±0.03	0.47	2
17878 <sup>†</sup>	(17878) 1999 AR25	2.34	0.22	1.57	335.1	289.3	K134I	2.8 <sup>w</sup>	2.70	1.88	13.88	14.96±0.22	4	43	19.22±0.06	11.78±0.01	0.42	2
18123	(18123) Pavan	2.96	0.08	1.29	201.1	101.5	K134I	4.6 <sup>w</sup>	3.20	2.42	12.73	13.57±0.07	4	36	18.77±0.04	4.82±0.03	0.13	2
18186	(18186) 2000 QW50	2.97	0.09	2.38	103.3	102.6	K134I	7.0 <sup>w</sup>	2.92	2.10	12.83	14.12±0.25	4	56	18.74±0.04	7.30±0.01	0.38	3
18482	(18482) 1995 YO	3.17	0.09	10.39	109.0	291.5	K134I	14.3 <sup>w</sup>	3.08	2.30	13.07	12.90±0.08	4	54	17.91±0.02	10.62±0.08	0.24	2
18602	(18602) Lagillespie	2.42	0.13	3.69	102.4	105.1	K134I	2.7 <sup>w</sup>	2.38	1.62	18.21	14.96±0.47	4	45	18.77±0.04	5.76±0.01	0.99	3
18692	(18692) 1998 HJ14	3.06	0.10	11.84	122.3	155.7	K134I	6.5 <sup>w</sup>	3.33	2.47	9.79	13.54±0.13	4	56	18.72±0.04	3.07±0.01	0.16	2
18852	(18852) 1999 RP91	3.18	0.16	1.44	56.8	236.2	K134I	12.0 <sup>w</sup>	3.68	2.92	10.99	12.98±0.23	4	46	18.75±0.05	9.66±0.05	0.63	3

Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\triangle$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
19332 <sup>†</sup>	(19332) 1996 YQ1	2.53	0.25	8.23	122.5	306.7	K134I	3.8 <sup>w</sup>	2.10	1.23	16.89	14.21±0.16	4	64	17.08±0.01	14.18±0.23	0.31	2
19653	(19653) 1999 RD119	2.53	0.11	14.21	294.4	100.5	K134I	5.4 <sup>w</sup>	2.46	1.70	17.80	13.35±0.12	4	49	17.40±0.02	2.61±0.01	0.13	2
19902	(19902) 3420 T-3	2.44	0.13	2.34	145.1	318.0	K134I	2.5 <sup>w</sup>	2.14	1.29	17.68	14.95±0.21	4	47	18.11±0.03	8.32±0.03	0.44	3
22418	(22418) 1995 WM4	2.59	0.16	4.27	100.1	236.0	K134I	3.4 <sup>w</sup>	2.85	2.13	15.73	13.99±0.17	3	44	18.77±0.05	3.22±0.01	0.27	2
23097	(23097) 1999 XF157	2.61	0.10	4.97	128.4	232.4	K134I	4.1 <sup>w</sup>	2.74	1.87	11.88	14.05±0.17	4	52	18.34±0.03	13.22±0.07	0.41	2
23678	(23678) 1997 GW32	2.62	0.11	1.77	336.0	336.9	K134I	2.7 <sup>w</sup>	2.90	2.12	14.03	14.95±0.39	4	33	19.81±0.10	8.01±0.04	1.03	3
24869	(24869) 1996 FZ	2.70	0.09	1.12	321.3	0.0	K134I	3.5 <sup>w</sup>	2.92	2.07	11.83	14.34±0.19	4	52	18.96±0.05	6.18±0.02	0.35	2
25028	(25028) 1998 QL26	2.65	0.12	4.34	126.5	266.3	K134I	3.2 <sup>w</sup>	2.60	1.78	14.91	14.87±0.21	4	44	19.02±0.06	5.88±0.01	0.54	3
25094	(25094) Zemtsov	2.64	0.05	2.98	298.3	329.4	K134I	6.2	2.77	2.02	15.73	14.06±0.43	4	43	18.67±0.04	5.18±0.01	0.92	3
25600	(25600) 2000 AS1	2.21	0.17	4.85	113.5	205.8	K134I	3.3	2.55	1.79	17.13	14.43±0.33	4	38	18.63±0.04	5.02±0.03	0.74	2
26031	(26031) 6074 P-L	2.17	0.15	0.66	341.9	341.5	K134I	1.6	2.47	1.66	16.12	15.99±0.34	4	34	19.92±0.10	4.55±0.02	0.73	2
26038	(26038) 2290 T-1	2.62	0.10	3.58	128.1	10.9	K134I	4.1	2.37	1.50	14.04	14.97±0.24	4	43	18.49±0.04	8.07±0.03	0.50	2
26098	(26098) 1989 AN3	2.28	0.15	5.30	117.6	293.1	K134I	3.5 <sup>w</sup>	2.11	1.36	21.82	14.10±0.13	4	46	17.43±0.02	2.42±0.00	0.12	2
26110 <sup>✓</sup>	(26110) 1991 NK4	2.22	0.21	6.79	123.1	176.9	K134I	3.8 <sup>w</sup>	2.67	1.79	11.76	14.01±0.35	4	24	18.36±0.02	4.57±0.02	0.72	2
28103	(28103) Benmcpheron	2.25	0.12	2.76	114.5	344.3	K134I	2.4 <sup>w</sup>	2.00	1.23	22.87	15.45±0.10	4	48	18.54±0.04	5.05±0.02	0.28	2
28715	(28715) 2000 GW103	2.79	0.05	2.74	122.5	172.3	K13B4	3.6	2.94	2.11	12.51	15.23±0.28	4	43	19.93±0.09	4.99±0.02	0.50	2
29516	(29516) 1997 YO7	2.98	0.06	11.68	103.4	37.4	K134I	6.4 <sup>w</sup>	2.84	2.19	17.33	13.48±0.19	4	55	18.35±0.04	9.86±0.06	0.34	2
29913	(29913) 1999 JO12	3.01	0.14	11.49	109.8	272.9	K134I	7.2 <sup>w</sup>	2.94	2.22	15.23	13.31±0.21	4	48	18.21±0.04	5.62±0.03	0.21	2
29953	(29953) 1999 JW86	3.02	0.15	10.85	107.8	253.4	K134I	6.9 <sup>w</sup>	3.06	2.43	15.94	13.48±0.42	4	48	18.60±0.05	8.54±0.03	0.97	2
30214	(30214) 2000 GS125	2.30	0.14	7.37	110.8	243.6	K134I	3.2 <sup>w</sup>	2.48	1.63	14.42	14.04±0.23	4	47	17.91±0.02	8.23±0.02	0.45	3
30780	(30780) 1988 CA2	2.34	0.06	7.11	124.2	334.6	K134I	2.2 <sup>w</sup>	2.21	1.37	16.80	14.59±0.17	4	51	17.90±0.02	5.09±0.02	0.09	2
30781	(30781) 1988 CR2	2.34	0.13	6.52	115.1	247.6	K134I	3.2 <sup>w</sup>	2.44	1.66	17.45	14.30±0.28	4	47	18.26±0.03	5.81±0.01	0.57	3
30990	(30990) 1995 ST48	2.98	0.16	2.45	97.6	119.8	K134I	7.0 <sup>w</sup>	2.96	2.14	12.49	14.44±0.22	4	48	19.19±0.05	4.61±0.02	0.23	2
31332	(31332) 1998 HC101	3.04	0.18	1.66	32.6	126.3	K134I	7.4 <sup>w</sup>	2.55	1.70	13.86	14.06±0.12	4	54	18.06±0.03	7.17±0.02	0.29	2



Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
31668	(31668) 1999 JX3	3.01	0.13	11.16	117.2	239.9	K134I	8.8 <sup>w</sup>	3.17	2.37	12.27	12.91±0.12	4	52	17.96±0.03	11.71±0.06	0.40	2
31737	(31737) 1999 JT75	2.38	0.08	6.01	317.3	126.7	K134I	3.6 <sup>w</sup>	2.23	1.37	15.53	14.54±0.18	4	45	17.78±0.02	6.93±0.03	0.52	2
32060	(32060) 2000 JN46	2.91	0.19	1.41	100.7	229.2	K134I	7.5	3.35	2.52	10.63	14.38±0.19	4	38	19.70±0.09	2.88±0.01	0.39	2
32226	(32226) 2000 OQ23	2.32	0.11	4.20	302.7	321.3	K134I	3.8 <sup>w</sup>	2.54	1.77	17.05	14.55±0.16	4	48	18.70±0.04	2.57±0.00	0.32	3
32232	(32232) 2000 OU27	2.40	0.13	7.26	131.4	235.0	K134I	4.1 <sup>w</sup>	2.51	1.67	14.69	13.74±0.15	4	47	17.68±0.02	5.68±0.01	0.36	3
32882	(32882) 1993 RW6	2.40	0.18	1.66	221.6	192.5	K134I	2.7 <sup>w</sup>	2.16	1.38	20.35	14.97±0.16	3	43	18.31±0.03	3.07±0.01	0.21	2
33343	(33343) 1998 XT10	2.32	0.07	7.28	121.6	68.9	K134I	1.6 <sup>w</sup>	2.24	1.40	16.73	15.37±0.13	4	52	18.76±0.04	6.21±0.03	0.14	2
33764	(33764) 1999 RM92	3.22	0.10	0.30	195.6	20.4	K134I	11.7 <sup>w</sup>	3.30	2.67	14.70	13.29±0.16	4	42	18.83±0.05	7.04±0.03	0.31	2
34232	(34232) 2000 QL94	2.98	0.09	10.72	122.9	207.1	K134I	5.7 <sup>w</sup>	3.21	2.38	11.05	13.97±0.33	4	43	19.05±0.06	6.78±0.04	0.57	3
34331	(34331) 2000 QH209	2.38	0.13	1.73	288.0	220.0	K134I	2.2 <sup>w</sup>	2.09	1.21	15.79	15.15±0.12	4	53	18.03±0.02	5.39±0.06	0.16	2
34426	(34426) 2000 SS22	3.14	0.12	1.84	124.6	351.8	K134I	10.1 <sup>w</sup>	2.75	2.09	17.56	14.26±0.31	4	37	19.01±0.06	6.40±0.01	0.86	2
34978	(34978) 1901 T-3	3.17	0.03	8.25	299.2	193.3	K13B4	10.3 <sup>w</sup>	3.07	2.27	12.44	13.54±0.20	4	53	18.48±0.03	14.52±0.76	0.31	2
35373	(35373) 1997 UT25	2.36	0.22	1.26	249.6	126.6	K134I	1.8	2.38	1.57	16.63	15.78±0.25	4	37	19.49±0.07	4.85±0.02	0.55	2
35475	(35475) 1998 EP9	2.44	0.14	3.30	111.8	85.2	K134I	2.3 <sup>w</sup>	2.28	1.41	14.85	14.76±0.12	4	55	18.12±0.03	4.96±0.01	0.15	2
35797	(35797) 1999 JY31	2.42	0.16	2.41	146.3	245.2	K134I	3.0 <sup>w</sup>	2.36	1.55	17.02	14.39±0.18	4	53	18.13±0.03	3.52±0.01	0.29	3
36061	(36061) Haldane	3.26	0.06	3.51	108.6	28.7	K134I	8.2	3.06	2.27	12.90	14.19±0.16	4	48	19.12±0.05	8.47±0.07	0.26	2
36187	(36187) Travisbarman	3.20	0.17	7.07	126.7	145.9	K134I	12.7 <sup>w</sup>	3.68	2.88	10.07	13.13±0.26	4	50	18.89±0.05	8.65±0.03	0.51	3
36224	(36224) 1999 TE268	3.25	0.07	12.59	290.0	273.8	K134I	8.8 <sup>w</sup>	3.26	2.59	14.45	13.78±0.27	4	31	19.22±0.07	15.46±0.25	0.64	2
36721	(36721) 2000 RK42	3.08	0.19	8.54	299.7	28.1	K134I	10.7	3.54	2.76	11.19	13.61±0.20	4	42	19.25±0.05	3.29±0.02	0.23	2
36886	(36886) 2000 SV161	3.07	0.07	11.78	102.7	190.2	K134I	5.8 <sup>w</sup>	3.29	2.63	14.51	13.94±0.22	3	36	19.41±0.07	7.03±0.06	0.41	2
37346	(37346) 2001 SU154	2.89	0.04	1.15	344.3	296.8	K13B4	3.6 <sup>w</sup>	2.99	2.13	11.08	14.38±0.20	4	38	19.07±0.05	3.26±0.00	0.44	3
37504	(37504) 3052 T-2	3.09	0.26	3.86	124.4	314.4	K134I	6.8	2.44	1.60	14.79	14.60±0.11	4	49	18.36±0.03	3.16±0.01	0.15	2
38176	(38176) 1999 JR119	2.45	0.18	3.10	112.0	218.4	K13B4	2.5	2.82	1.99	12.68	15.06±0.30	4	66	19.55±0.07	5.27±0.01	0.62	3
38533 <sup>†</sup>	(38533) 1999 UQ33	3.24	0.11	0.24	49.7	167.6	K134I	7.9	3.25	2.44	11.52	14.28±0.29	4	45	19.42±0.06	20.65±0.81	0.56	2

Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
38663	(38663) 2000 OK49	2.39	0.26	5.84	120.1	187.8	K134I	2.4	2.99	2.21	13.29	15.10±0.37	4	30	20.15±0.10	5.51±0.02	0.97	2
39339	(39339) 2002 AD32	3.17	0.14	2.55	88.3	20.3	K134I	5.6	2.73	2.01	16.49	15.00±0.23	3	22	19.63±0.09	4.61±0.04	0.55	2
39864	(39864) Poggiali	2.98	0.09	11.23	110.8	285.1	K134I	9.3	2.92	2.13	13.88	13.92±0.14	2	28	18.64±0.04	8.36±0.04	0.33	2
41006	(41006) 1999 UM13	2.53	0.14	1.70	299.1	9.9	K134I	2.4 <sup>w</sup>	2.86	2.10	14.58	15.24±0.37	3	30	19.93±0.10	3.33±0.01	1.01	2
43537	(43537) 2001 EF2	2.62	0.20	18.34	119.4	201.0	K134I	6.8 <sup>w</sup>	3.09	2.30	12.73	13.94±0.17	3	27	18.94±0.05	3.76±0.03	0.28	2
44579	(44579) 1999 GR25	2.89	0.04	3.18	126.7	122.6	K13B4	4.9 <sup>w</sup>	2.95	2.10	11.41	14.07±0.35	4	58	18.71±0.04	4.60±0.01	0.67	3
45929	(45929) 2000 YP116	2.54	0.11	14.50	120.1	100.4	K134I	2.8 <sup>w</sup>	2.55	1.72	14.59	14.66±0.43	4	50	18.65±0.03	6.77±0.01	0.93	3
46620 <sup>†</sup>	(46620) 1994 EL1	2.19	0.14	4.93	112.7	317.5	K134I	3.9 <sup>w</sup>	1.99	1.16	20.41	14.01±0.11	3	48	16.96±0.01	12.17±0.03	0.25	2
47026	(47026) 1998 VS21	2.69	0.03	3.39	291.4	333.0	K134I	4.9	2.76	1.93	13.07	14.57±0.14	4	51	18.94±0.05	5.12±0.06	0.24	2
47149*	(47149) 1999 RX34	2.13	0.18	2.01	82.3	233.7	K134I	2.7 <sup>w</sup>	2.51	1.65	13.53	14.87±0.32	4	37	18.65±0.03	9.50±0.05	0.56	3
48902	(48902) 1998 MP31	2.22	0.22	5.35	290.6	36.0	K134I	3.2 <sup>w</sup>	2.58	1.87	18.05	14.60±0.25	4	42	18.91±0.05	5.44±0.02	0.39	2
49719	(49719) 1999 VE50	2.16	0.10	2.26	306.3	173.7	K134I	2.6 <sup>w</sup>	1.95	1.10	20.10	15.02±0.10	4	58	17.69±0.02	1.24±0.00	0.10	2
49766*	(49766) 1999 WS	2.14	0.12	1.36	356.1	280.2	K134I	2.4 <sup>w</sup>	2.38	1.58	17.17	15.19±0.39	4	38	18.98±0.06	6.82±0.04	0.79	3
50031	(50031) 2000 AH47	2.69	0.05	13.43	116.7	119.3	K13B4	3.1 <sup>w</sup>	2.76	2.01	15.70	14.59±0.28	4	42	19.23±0.07	6.61±0.02	0.76	3
50038	(50038) 2000 AT54	2.68	0.16	6.71	106.7	178.0	K134I	8.5 <sup>w</sup>	3.08	2.32	13.36	14.36±0.39	4	48	19.45±0.06	7.26±0.02	0.68	3
50350	(50350) 2000 CD70	2.74	0.13	8.32	300.7	330.0	K13B4	6.6	3.06	2.32	14.01	13.91±0.34	4	52	18.95±0.06	5.75±0.02	0.75	3
50413	(50413) Petrginz	2.72	0.17	9.96	121.4	236.6	K134I	3.3 <sup>w</sup>	2.90	2.09	13.18	14.66±0.31	4	46	19.30±0.06	4.80±0.03	0.56	2
50762	(50762) 2000 EY184	2.75	0.08	13.47	114.0	290.8	K13B4	4.2	2.65	1.93	17.22	14.91±0.26	4	60	19.30±0.06	3.18±0.01	0.24	2
52437	(52437) 1994 PY27	2.25	0.09	5.06	127.9	117.1	K134I	1.6	2.35	1.56	17.48	15.95±0.32	4	40	19.69±0.09	5.02±0.01	0.72	3
53298	(53298) 1999 GF25	2.90	0.01	3.21	125.7	323.6	K13B4	6.5 <sup>w</sup>	2.88	2.08	13.59	13.45±0.26	4	74	18.11±0.02	5.51±0.01	0.43	3
54579	(54579) 2000 QA165	3.03	0.05	10.81	299.1	144.5	K134I	4.6 <sup>w</sup>	2.91	2.07	12.00	14.23±0.17	4	54	18.87±0.04	4.76±0.03	0.25	2
54704	(54704) 2001 FC172	2.71	0.16	16.49	113.9	218.2	K134I	4.0 <sup>w</sup>	3.01	2.28	14.52	14.25±0.52	4	45	19.30±0.07	2.91±0.01	0.39	2
55002	(55002) 2001 QF19	2.88	0.04	1.25	227.1	215.8	K134I	7.5	2.78	1.98	14.33	14.39±0.11	4	46	18.90±0.05	4.56±0.02	0.18	2
55004	(55004) 2001 QT22	2.90	0.10	3.33	109.8	290.6	K134I	9.0	2.81	2.05	15.28	13.99±0.19	4	47	18.64±0.04	3.81±0.01	0.39	3

Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
55497	(55497) 2001 UA83	2.95	0.04	3.18	116.0	143.4	K134I	5.3	3.03	2.19	11.82	15.12±0.23	3	43	19.96±0.09	3.21±0.01	0.40	2
55776 <sup>†</sup>	(55776) 1993 FH14	2.26	0.07	4.74	123.2	84.3	K134I	1.7 <sup>w</sup>	2.23	1.36	15.65	15.79±0.20	4	49	18.93±0.04	13.35±0.13	0.43	2
56080	(56080) 1999 AN3	2.31	0.15	3.34	309.0	101.2	K13B4	2.8 <sup>w</sup>	2.18	1.32	16.68	14.65±0.15	4	65	17.84±0.02	4.75±0.01	0.33	3
56093	(56093) 1999 BM5	2.33	0.22	1.36	104.1	263.5	K134I	2.5	2.37	1.65	19.52	15.02±0.29	4	51	18.96±0.05	4.83±0.01	0.63	3
56264	(56264) 1999 JV95	3.01	0.12	11.73	124.7	226.8	K134I	6.3	3.22	2.39	11.14	14.77±0.24	4	42	19.93±0.10	17.27±0.31	0.65	2
56501 <sup>†</sup>	(56501) 2000 GG153	2.26	0.05	4.29	304.4	135.3	K134I	2.0 <sup>w</sup>	2.18	1.35	17.95	15.78±0.30	4	31	19.39±0.05	19.32±0.04	0.78	2
56585	(56585) 2000 JZ29	2.31	0.13	5.07	302.4	90.3	K134I	2.6	2.24	1.49	20.08	14.94±0.35	4	49	18.50±0.04	5.67±0.01	0.74	3
58541	(58541) 1997 EA18	3.12	0.11	1.57	22.5	147.4	K13B4	7.4 <sup>w</sup>	2.89	2.08	13.44	14.41±0.30	4	84	19.07±0.05	7.69±0.01	0.65	3
60637	(60637) 2000 FX30	2.22	0.11	3.78	107.2	20.7	K134I	3.5 <sup>w</sup>	1.99	1.12	18.13	16.19±0.14	4	52	18.87±0.04	3.23±0.01	0.16	2
61303	(61303) 2000 OY47	2.41	0.23	4.25	127.7	204.6	K134I	2.2	2.83	2.03	13.79	15.29±0.41	4	42	19.88±0.10	4.62±0.05	0.74	2
61397	(61397) 2000 QF5	2.42	0.22	1.48	315.0	37.2	K134I	2.5	2.66	1.86	15.21	15.00±0.29	4	49	19.31±0.07	6.94±0.02	0.65	3
61479	(61479) 2000 QH39	2.39	0.11	1.77	289.5	88.6	K134I	2.7 <sup>w</sup>	2.45	1.57	13.49	15.57±0.33	4	48	19.22±0.06	4.89±0.02	0.57	3
62213	(62213) 2000 SL63	3.11	0.11	3.51	123.7	272.4	K134I	5.3 <sup>w</sup>	3.04	2.22	12.13	14.32±0.21	4	48	19.21±0.05	3.68±0.02	0.32	2
62828	(62828) 2000 UN53	3.20	0.16	3.08	133.9	328.4	K134I	7.4 <sup>w</sup>	2.72	1.86	12.23	14.23±0.18	4	59	18.44±0.03	11.03±0.14	0.26	2
62854	(62854) 2000 UW76	3.15	0.12	1.34	152.9	347.8	K13B4	5.8	2.79	1.96	13.06	14.95±0.31	4	46	19.34±0.07	14.72±0.16	0.56	2
63660	(63660) 2001 QV119	2.89	0.05	3.31	96.1	321.1	K134I	4.7 <sup>w</sup>	2.83	2.01	13.34	13.59±0.10	3	47	18.15±0.03	14.39±0.20	0.26	2
63736	(63736) 2001 QF249	3.03	0.23	2.81	88.5	338.5	K134I	7.4	2.53	1.71	14.99	14.41±0.27	4	42	18.47±0.04	4.13±0.03	0.40	2
63968	(63968) 2001 SG71	2.33	0.07	7.20	119.3	26.9	K134I	1.8 <sup>w</sup>	2.17	1.31	17.04	15.20±0.23	4	56	18.35±0.03	3.19±0.00	0.60	3
64301	(64301) 2001 UN19	2.28	0.17	3.69	115.9	44.3	K134I	1.5 <sup>w</sup>	1.98	1.28	25.22	16.12±0.46	4	31	19.26±0.09	6.51±0.01	0.87	2
64379	(64379) 2001 UG123	3.05	0.19	1.47	77.4	23.2	K134I	6.1	2.49	1.66	15.20	14.85±0.26	4	43	18.68±0.04	12.82±0.07	0.69	2
64391	(64391) 2001 UF150	2.32	0.06	0.89	75.2	75.3	K134I	1.7 <sup>w</sup>	2.19	1.34	16.89	16.20±0.31	4	52	19.40±0.08	6.85±0.02	0.68	2
64897	(64897) 2001 YX81	2.38	0.21	1.65	343.4	63.4	K134I	1.8	2.16	1.34	18.98	15.73±0.13	4	54	19.00±0.05	5.30±0.04	0.15	2
64941	(64941) 2001 YJ118	3.12	0.15	9.11	311.4	285.6	K134I	9.4 <sup>w</sup>	3.27	2.44	10.95	13.98±0.27	4	48	19.19±0.05	9.38±0.04	0.52	3
65155	(65155) 2002 CP140	3.23	0.08	8.55	292.1	274.3	K134I	5.7 <sup>w</sup>	3.24	2.57	14.40	14.47±0.27	3	36	19.85±0.11	4.78±0.02	0.71	2

Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
65191	(65191) 2002 CR257	3.17	0.18	0.35	163.1	179.1	K134I	6.8 <sup>w</sup>	3.53	2.72	10.54	14.76±0.28	3	22	20.38±0.11	5.46±0.03	0.59	2
65465	(65465) 2002 XQ20	2.81	0.03	2.64	302.5	276.5	K13B4	5.5	2.82	1.99	13.09	15.06±0.23	4	40	19.51±0.07	3.63±0.01	0.55	3
66189	(66189) 1998 XA97	2.31	0.12	7.01	110.8	157.5	K13B4	1.7 <sup>w</sup>	2.53	1.68	14.35	15.89±0.22	4	55	19.83±0.08	7.88±0.03	0.42	3
66372	(66372) 1999 JV114	2.38	0.15	2.77	293.9	281.8	K134I	2.0 <sup>w</sup>	2.34	1.51	16.37	15.10±0.27	4	45	18.64±0.04	8.02±0.05	0.57	3
66545	(66545) 1999 RJ120	2.54	0.19	1.89	175.1	186.4	K134I	3.1	2.66	1.91	16.50	15.57±0.30	4	38	19.92±0.10	14.81±0.38	0.75	2
66732	(66732) 1999 TW111	2.58	0.23	1.98	273.6	167.2	K134I	5.2 <sup>w</sup>	2.10	1.28	19.73	15.75±0.23	3	34	18.87±0.05	8.55±0.02	0.65	3
66868	(66868) 1999 VS47	2.57	0.18	7.94	312.3	51.1	K134I	5.9 <sup>w</sup>	2.75	1.89	12.31	15.34±0.16	2	33	19.64±0.07	6.23±0.06	0.31	2
67466	(67466) 2000 QJ217	2.48	0.15	4.09	277.8	58.9	K134I	3.3 <sup>w</sup>	2.75	1.97	15.03	14.42±0.26	4	48	18.89±0.05	3.15±0.01	0.53	3
69661	(69661) 1998 FZ117	2.48	0.13	3.61	290.5	284.2	K134I	1.6	2.45	1.64	16.24	16.05±0.34	4	36	19.73±0.09	16.49±0.22	1.44	2
72713 <sup>†</sup>	(72713) 2001 FQ86	2.59	0.20	8.11	116.6	2.8	K134I	3.8	2.08	1.27	20.13	15.11±0.31	4	56	18.21±0.03	11.90±0.07	9.69	2
75640 <sup>†b</sup>	(75640) 2000 AE55	2.67	0.12	13.06	118.4	101.9	K134I	3.9 <sup>w</sup>	2.70	1.92	15.07	14.16±0.25	4	54	18.74±0.04	12.34±0.08	0.70	2
75872	(75872) 2000 CK24	2.70	0.18	11.83	308.9	51.3	K134I	4.3 <sup>w</sup>	2.87	2.06	13.43	14.21±0.17	1	21	18.88±0.05	3.80±0.12	0.44	2
76173	(76173) 2000 EE32	2.69	0.13	5.77	129.6	352.4	K134I	3.4	2.36	1.50	15.10	15.37±0.15	4	49	18.93±0.04	3.11±0.01	0.25	2
76417	(76417) 2000 FW18	2.76	0.05	10.43	110.7	127.1	K134I	3.9	2.82	2.04	14.60	15.07±0.20	4	43	19.69±0.08	4.35±0.02	0.29	2
76470	(76470) 2000 FC57	2.74	0.01	3.90	283.8	123.2	K134I	5.3	2.73	1.91	14.01	14.37±0.28	4	52	18.71±0.04	7.22±0.02	0.63	3
76668	(76668) 2000 HA45	2.77	0.13	4.27	105.9	132.4	K134I	5.4 <sup>w</sup>	2.89	2.06	12.48	15.17±0.26	4	44	19.71±0.08	9.50±0.04	0.58	2
77313 <sup>✓</sup>	(77313) 2001 FY81	2.58	0.14	6.74	307.1	247.3	K134I	3.5	2.41	1.53	13.93	15.27±0.33	4	50	18.84±0.06	6.42±0.03	0.48	2
77880	(77880) 2001 SE121	2.80	0.20	5.73	292.6	285.4	K134I	6.4	2.83	2.09	15.58	14.75±0.27	4	44	19.41±0.08	8.38±0.06	0.40	2
78130	(78130) 2002 NL12	2.55	0.20	5.81	115.2	136.8	K134I	2.6 <sup>w</sup>	2.84	2.05	14.08	15.43±0.32	4	36	20.09±0.11	5.22±0.02	0.53	2
78299	(78299) 2002 PF55	2.76	0.21	9.70	298.6	75.0	K134I	5.5	2.75	2.01	15.94	14.30±0.14	4	37	18.86±0.04	4.60±0.02	0.21	2
78381	(78381) 2002 PQ135	2.76	0.23	1.39	352.8	59.1	K134I	3.3	2.42	1.60	16.15	15.39±0.16	4	37	19.21±0.05	17.91±0.49	0.44	2
78657	(78657) 2002 TS76	2.73	0.09	3.91	294.6	352.3	K134I	5.4 <sup>w</sup>	2.97	2.24	14.72	14.88±0.23	4	42	19.76±0.08	4.65±0.02	0.49	2
78765	(78765) 2002 UD36	2.75	0.07	4.64	316.3	202.0	K134I	5.2 <sup>w</sup>	2.60	1.75	13.66	15.25±0.31	4	49	19.26±0.06	5.74±0.01	0.74	3
80276	(80276) 1999 XL32	2.67	0.12	16.45	116.7	94.6	K13B4	3.7 <sup>w</sup>	2.65	1.87	15.48	14.18±0.33	4	65	18.56±0.04	5.56±0.01	0.73	3

Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
83422	(83422) 2001 SV43	2.91	0.06	2.97	133.0	315.5	K134I	6.6	2.78	1.92	12.01	14.67±0.29	4	54	18.90±0.05	9.64±0.07	0.55	3
86696	(86696) 2000 FO49	2.26	0.10	4.39	302.1	297.7	K13B4	2.2 <sup>w</sup>	2.32	1.46	14.69	15.42±0.50	4	41	18.86±0.05	4.87±0.01	0.96	2
86725	(86725) 2000 GG32	2.80	0.09	0.60	70.0	298.4	K134I	4.2 <sup>w</sup>	2.86	2.10	14.85	15.90±0.26	4	34	20.57±0.13	6.47±0.04	0.61	2
87086	(87086) 2000 KZ81	2.29	0.10	3.49	330.3	358.5	K134I	2.0	2.50	1.66	14.55	15.51±0.12	4	51	19.42±0.06	3.23±0.01	0.18	2
87642	(87642) 2000 RF73	2.44	0.16	0.91	345.6	97.1	K13B4	2.2	2.13	1.27	16.87	15.30±0.24	4	70	18.35±0.03	4.61±0.01	0.49	3
88628	(88628) 2001 RF34	2.24	0.09	6.30	295.1	215.2	K134I	2.7 <sup>w</sup>	2.05	1.25	20.67	15.73±0.34	4	44	18.73±0.05	5.90±0.01	0.77	3
91305	(91305) 1999 FK46	2.34	0.08	2.24	109.7	341.8	K134I	2.2 <sup>w</sup>	2.20	1.33	15.81	16.20±0.31	4	39	19.34±0.06	15.53±0.22	0.68	2
92460	(92460) 2000 KT39	2.28	0.09	3.96	117.7	102.8	K134I	1.4	2.30	1.51	18.35	16.26±0.23	4	35	19.93±0.09	7.63±0.10	0.33	2
92754	(92754) 2000 QY113	2.38	0.13	1.66	280.7	248.1	K134I	1.9 <sup>w</sup>	2.16	1.40	21.12	15.64±0.41	4	43	18.99±0.07	6.03±0.01	0.95	3
92857	(92857) 2000 QQ205	2.43	0.18	2.35	151.9	294.5	K134I	1.8	2.06	1.23	19.79	15.73±0.25	4	46	18.71±0.04	5.01±0.02	0.47	3
95010	(95010) 2002 AR1	2.40	0.16	2.26	122.1	297.6	K134I	1.7	2.13	1.43	22.98	15.81±0.42	4	27	19.31±0.08	8.64±0.05	1.14	2
95110	(95110) 2002 AR118	2.41	0.17	3.39	114.4	324.0	K134I	1.5	2.06	1.34	23.31	16.15±0.36	4	25	19.51±0.09	6.82±0.03	0.79	2
96885	(96885) 1999 TK26	2.58	0.08	1.22	332.6	130.9	K134I	3.5	2.38	1.59	17.59	15.30±0.31	4	40	19.12±0.05	10.34±0.15	0.23	3
96893 <sup>†</sup>	(96893) 1999 TM39	2.59	0.09	7.24	110.0	342.3	K134I	3.5	2.37	1.60	18.40	15.31±0.44	4	43	19.59±0.06	12.24±0.05	0.82	2
98869	(98869) 2001 BT5	2.55	0.19	15.05	108.0	291.1	K134I	3.6	2.32	1.65	21.49	15.20±0.37	4	34	19.13±0.07	4.68±0.01	0.77	3
A0830	(100830) 1998 HV9	3.05	0.12	4.57	133.3	324.6	K134I	5.7	2.70	1.89	14.43	14.98±0.17	4	47	19.34±0.06	9.00±0.06	0.29	2
A2727	(102727) 1999 VF101	2.58	0.04	1.73	40.3	287.3	K134I	2.4	2.66	1.82	13.39	16.15±0.39	4	33	20.26±0.13	9.40±0.04	1.09	3
A3066	(103066) 1999 XO141	1.67	0.17	2.94	111.3	192.4	K134I	0.8	1.96	1.09	18.18	17.63±0.42	3	19	20.11±0.11	5.53±0.03	0.89	2
A3113	(103113) 1999 XD178	2.65	0.05	21.30	297.5	139.3	K134I	3.7	2.56	1.75	15.51	15.15±0.27	4	37	19.23±0.06	3.82±0.02	0.40	2
A4718	(104718) 2000 GQ174	2.75	0.08	1.71	22.0	328.8	K134I	3.5	2.89	2.06	12.73	15.31±0.29	4	43	19.92±0.09	7.57±0.03	0.58	2
A5291	(105291) 2000 QY47	3.05	0.09	2.53	145.0	280.8	K134I	7.2	2.86	2.07	13.85	14.49±0.47	4	41	19.06±0.06	5.19±0.02	1.04	3
A5312	(105312) 2000 QC71	3.00	0.02	1.04	103.2	346.5	K13B4	4.9	2.94	2.11	12.20	15.33±0.31	4	74	20.01±0.10	8.91±0.06	0.62	3
A5774	(105774) 2000 SX111	3.15	0.20	1.06	52.8	343.6	K134I	5.5	2.98	2.16	12.35	15.05±0.25	4	41	19.84±0.10	10.04±0.10	0.63	2
A6203	(106203) 2000 UB23	2.47	0.17	3.42	122.7	281.8	K134I	1.5	2.29	1.54	19.58	16.17±0.31	4	35	19.88±0.10	5.69±0.01	0.77	2

Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
A6661	(106661) 2000 WH144	3.17	0.24	10.56	116.8	260.0	K134I	6.9	3.15	2.34	12.06	14.56±0.28	4	43	19.61±0.08	5.40±0.02	0.66	2
A7632	(107632) 2001 EX11	2.57	0.07	2.26	101.8	42.2	K134I	2.9	2.40	1.54	14.25	15.72±0.39	4	51	19.33±0.06	5.52±0.03	0.70	2
A8516	(108516) 2001 KR75	2.32	0.33	22.19	296.3	72.3	K13B4	3.1	2.32	1.55	18.79	14.52±0.24	4	30	18.31±0.03	6.68±0.03	0.63	2
B1139	(111139) 2001 VS95	2.96	0.06	11.04	120.4	123.9	K134I	3.7 <sup>w</sup>	3.05	2.21	11.42	15.03±0.41	4	40	19.86±0.08	6.74±0.03	0.86	3
B5807	(115807) 2003 UJ238	2.63	0.12	1.42	39.9	358.9	K13B4	2.7	2.56	1.72	14.20	15.83±0.25	4	40	19.91±0.09	5.20±0.02	0.46	2
B7526	(117526) 2005 CS57	2.57	0.05	7.60	295.6	309.1	K134I	3.8 <sup>w</sup>	2.63	1.79	13.67	16.09±0.30	4	35	20.11±0.12	6.62±0.05	0.81	2
B8264	(118264) 1998 FB105	3.00	0.24	7.05	307.1	290.8	K13B4	5.8	3.16	2.31	10.93	14.93±0.21	4	77	19.90±0.08	3.10±0.01	0.23	2
B8826	(118826) 2000 SV154	3.19	0.19	1.85	65.9	12.9	K134I	6.2	2.70	1.86	13.56	14.79±0.12	4	51	19.11±0.05	17.58±0.35	0.33	2
B9936 <sup>v</sup>	(119936) 2002 GC27	3.41	0.06	1.22	177.8	13.5	K134I	5.9 <sup>w</sup>	3.35	2.60	12.68	14.68±0.34	2	24	20.38±0.10	8.65±0.57	0.82	2
C1913	(121913) 2000 DN68	2.23	0.13	2.67	340.6	258.7	K134I	1.4 <sup>w</sup>	2.32	1.48	15.99	16.50±0.30	4	40	20.04±0.10	5.20±0.02	0.64	2
C3054	(123054) 2000 SH298	2.37	0.12	4.16	313.1	290.0	K134I	1.7 <sup>w</sup>	2.48	1.62	14.07	16.21±0.17	4	41	20.03±0.10	8.38±0.05	0.37	2
C3150	(123150) 2000 TJ32	2.40	0.14	3.66	287.1	254.7	K134I	1.5	2.21	1.43	19.74	16.20±0.33	4	27	19.67±0.10	4.25±0.01	0.93	3
C5091	(125091) 2001 UX24	2.31	0.13	6.58	299.0	87.5	K134I	1.9	2.31	1.47	15.98	15.61±0.29	3	29	19.08±0.04	4.45±0.11	0.71	3
C6311	(126311) 2002 AT123	2.39	0.18	1.73	324.6	120.5	K134I	1.4	2.04	1.19	18.19	16.35±0.18	4	46	19.17±0.06	4.92±0.01	0.44	3
C8799	(128799) 2004 RS225	2.38	0.20	0.95	347.4	8.9	K13B4	1.3	2.62	1.75	12.91	16.42±0.34	3	43	20.38±0.14	7.89±0.06	0.81	2
D0485	(130485) 2000 QN103	2.43	0.19	2.48	108.4	278.6	K134I	1.5	2.42	1.55	14.06	16.08±0.28	4	49	19.73±0.09	4.85±0.01	0.56	2
D0782	(130782) 2000 TH6	2.42	0.13	0.71	304.5	193.7	K134I	1.3	2.11	1.26	17.88	16.40±0.28	4	39	19.41±0.06	6.60±0.15	0.63	3
D3324 <sup>†</sup>	(133324) 2003 SY90	3.92	0.22	1.75	153.3	243.2	K134I	6.1	3.55	2.81	11.82	14.84±0.29	3	32	20.57±0.13	11.31±0.20	0.76	2
D8522	(138522) 2000 NW19	3.09	0.25	14.99	302.2	91.2	K134I	10.7	2.91	2.04	11.20	13.61±0.14	4	55	18.15±0.02	10.80±0.06	0.20	3
D8544	(138544) 2000 QY9	2.97	0.16	10.86	306.7	31.1	K134I	6.3	3.34	2.47	9.43	14.77±0.29	4	41	19.95±0.09	5.77±0.06	0.69	2
D9888	(139888) 2001 RC89	2.90	0.07	2.99	137.4	218.8	K134I	5.5	3.01	2.17	11.62	15.05±0.27	4	48	19.81±0.08	8.87±0.07	0.49	3
D9938	(139938) 2001 RQ134	2.92	0.08	6.08	121.9	317.5	K134I	5.3	2.72	1.93	14.68	15.15±0.22	4	39	19.52±0.07	5.40±0.05	0.50	2
E0251	(140251) 2001 SN255	2.28	0.10	2.15	128.2	53.7	K13B4	1.3	2.13	1.26	16.00	16.46±0.34	4	70	19.47±0.06	6.66±0.02	0.72	3
E3489	(143489) 2003 DS	2.97	0.06	9.62	303.7	318.5	K134I	5.0	3.10	2.24	10.48	15.29±0.21	4	42	20.12±0.10	3.30±0.01	0.33	2

Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
E5620	(145620) 2006 QE94	2.90	0.14	0.86	255.1	140.8	K134I	3.7	2.77	2.04	16.01	15.91±0.28	2	20	20.49±0.13	5.23±0.03	0.80	2
F1540*	(151540) 2002 SR14	2.12	0.09	2.20	96.5	201.5	K134I	1.0	2.32	1.45	14.99	16.99±0.26	3	27	20.43±0.11	5.87±0.04	0.66	2
F5095 <sup>∨</sup>	(155095) 2005 SJ193	2.24	0.16	1.11	288.1	126.7	K134I	1.0	2.05	1.24	20.15	17.04±0.45	3	32	19.96±0.11	16.22±2.46	1.06	2
F5613	(155613) 2000 EW13	2.22	0.13	4.51	125.3	308.4	K13B4	1.5	2.02	1.16	18.23	16.19±0.34	4	55	18.96±0.05	5.89±0.01	0.74	3
G2297	(162297) 1999 VU167	2.62	0.17	2.78	294.7	125.5	K134I	2.8	2.32	1.57	19.55	15.78±0.28	4	44	19.57±0.08	3.68±0.01	0.51	2
G3964	(163964) 2003 UR81	2.66	0.28	6.70	117.9	280.8	K134I	2.0	2.38	1.56	16.64	16.47±0.29	4	29	20.21±0.12	7.22±0.04	0.95	2
G4228	(164228) 2004 RC229	2.35	0.15	1.92	306.3	244.4	K13B4	1.4 <sup>w</sup>	2.17	1.34	17.74	16.66±0.39	4	69	19.95±0.10	6.25±0.02	0.75	3
H0711	(170711) 2004 BD40	2.77	0.10	3.01	294.7	117.2	K134I	2.9	2.63	1.87	16.30	15.67±0.24	4	36	20.02±0.11	3.17±0.01	0.43	2
H2279	(172279) 2002 TO121	2.77	0.06	6.26	318.5	87.9	K134I	2.8	2.73	1.89	13.43	15.81±0.17	4	46	20.17±0.10	7.83±0.08	0.21	2
H2699	(172699) 2004 BR23	2.78	0.09	3.63	125.2	76.4	K134I	4.2 <sup>w</sup>	2.72	1.89	13.75	15.86±0.40	4	40	20.17±0.11	8.44±0.09	0.79	2
H6537	(176537) 2002 AA17	3.12	0.15	18.54	118.4	34.1	K13B4	6.0	2.71	1.94	15.36	14.88±0.17	4	42	19.32±0.07	6.60±0.04	0.30	2
H9572	(179572) 2002 FY11	3.22	0.07	21.29	115.5	97.6	K134I	6.6 <sup>w</sup>	3.22	2.40	11.46	14.83±0.36	4	45	19.90±0.09	13.41±0.08	0.91	2
I4292	(184292) 2005 EK	2.56	0.13	3.31	314.8	262.1	K134I	2.6	2.57	1.78	16.22	15.94±0.29	3	35	20.13±0.10	4.34±0.02	0.41	2
J2534	(192534) 1998 SN80	2.24	0.17	4.84	305.1	56.4	K134I	1.1	2.39	1.56	15.83	16.84±0.28	3	31	20.56±0.14	8.42±0.10	0.70	2
J3008	(193008) 2000 EH16	2.21	0.15	2.87	338.6	115.5	K134I	1.0	1.91	1.04	18.82	16.98±0.33	4	52	19.43±0.08	5.85±0.01	0.69	3
J4458	(194458) 2001 VX124	2.34	0.08	5.72	306.8	122.9	K134I	1.2	2.21	1.45	20.17	16.58±0.40	4	27	20.13±0.10	6.52±0.03	1.30	3
J4547	(194547) 2001 XT67	2.38	0.16	2.25	113.3	321.4	K134I	1.2	2.09	1.30	20.91	16.66±0.29	4	33	19.79±0.09	4.92±0.02	0.76	3
J4912 <sup>†</sup>	(194912) 2002 AG114	2.38	0.12	5.73	307.7	80.0	K134I	1.7	2.40	1.51	13.38	15.90±0.38	4	44	19.45±0.07	12.68±0.08	0.91	2
J5227	(195227) 2002 DH18	2.42	0.17	0.79	210.7	236.5	K134I	0.9	2.06	1.26	20.54	17.30±0.29	3	32	20.43±0.11	5.03±0.09	0.55	2
J7868	(197868) 2004 RQ6	2.36	0.14	8.76	121.4	240.8	K13B4	1.4	2.49	1.65	14.52	16.24±0.36	4	43	20.00±0.11	4.68±0.02	0.93	2
K0772	(200772) 2001 XJ23	2.36	0.12	5.91	316.5	70.9	K134I	1.4	2.36	1.51	15.65	16.24±0.30	4	31	19.83±0.07	8.86±0.18	0.58	2
K0852	(200852) 2001 YD35	2.35	0.14	1.36	16.4	128.0	K134I	0.9	2.03	1.20	19.37	17.15±0.20	4	34	20.07±0.09	2.67±0.01	0.28	2
K09BI3U	2009 BU183	2.63	0.26	11.37	301.0	151.9	K134I	2.3	1.99	1.21	22.63	16.19±1.00	4	21	19.35±0.07	2.81±0.00	0.60	2
K13A27Y	2013 AY27	2.68	0.32	16.96	125.0	289.9	K13B4	1.5	2.17	1.32	16.94	17.06±0.30	3	36	20.24±0.11	2.47±0.01	0.63	2

Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
K2238	(202238) 2005 AC2	2.53	0.16	2.10	106.6	329.8	K134I	1.8	2.24	1.39	16.51	16.67±0.19	4	40	19.99±0.10	5.63±0.02	0.36	2
K3173	(203173) 2000 YL98	2.54	0.24	9.28	118.0	332.2	K134I	2.1	1.99	1.21	22.38	16.36±0.24	4	41	19.28±0.06	2.09±0.01	0.37	2
K3222	(203222) 2001 FH81	2.57	0.20	9.46	303.2	256.8	K134I	3.8 <sup>w</sup>	2.35	1.50	15.50	16.15±0.20	4	37	19.74±0.09	7.28±0.07	0.31	2
K6619	(206619) 2003 WS117	2.64	0.09	3.80	299.0	48.6	K13B4	2.2	2.80	1.97	13.12	16.27±0.32	4	35	20.78±0.15	5.90±0.04	0.85	2
K6698	(206698) 2004 AD13	2.73	0.06	5.70	111.3	225.2	K134I	3.4 <sup>w</sup>	2.85	2.05	13.83	15.87±0.22	1	19	20.44±0.11	3.44±0.08	0.52	2
K7121	(207121) 2005 AT58	2.54	0.11	1.98	99.9	328.6	K134I	1.9	2.36	1.56	17.49	16.61±0.27	3	30	20.37±0.12	5.90±0.04	0.56	2
K8096	(208096) 2000 AT88	2.67	0.17	10.95	292.6	139.1	K134I	6.1 <sup>w</sup>	2.34	1.55	18.07	15.98±0.30	4	33	19.75±0.09	8.74±0.04	0.73	2
K8102	(208102) 2000 BX2	2.67	0.05	4.92	118.5	343.4	K134I	2.3	2.55	1.67	12.58	16.24±0.34	4	45	20.05±0.09	5.13±0.02	0.65	2
K8150	(208150) 2000 FJ34	2.73	0.16	12.71	115.9	92.1	K134I	3.1	2.62	1.79	13.97	15.58±0.42	4	42	19.72±0.08	5.18±0.01	0.88	3
L1243	(211243) 2002 QJ30	2.70	0.13	6.07	122.8	318.4	K13B4	2.5	2.42	1.60	16.31	16.04±0.32	4	67	19.81±0.09	5.85±0.03	0.56	2
L3779	(213779) 2003 EP14	3.03	0.09	10.76	123.1	48.5	K134I	4.6	2.87	2.11	14.90	15.44±0.40	3	24	19.99±0.11	5.55±0.03	0.93	2
L3991	(213991) 2004 BK42	2.77	0.20	5.03	303.4	230.8	K134I	2.6	2.40	1.63	18.08	15.95±0.33	4	37	19.80±0.10	4.61±0.02	0.72	2
N8913	(238913) 2006 AE9	2.33	0.15	8.87	128.9	344.3	K134I	1.4	1.98	1.10	17.65	16.35±0.15	4	51	18.95±0.04	4.93±0.03	0.20	2
N9107	(239107) 2006 HH58	2.40	0.21	10.72	126.5	121.7	K134I	2.7 <sup>w</sup>	2.57	1.69	12.33	16.68±0.27	2	21	20.56±0.13	3.21±0.01	0.66	2
O0098	(240098) 2002 CP96	2.42	0.13	3.47	124.1	101.7	K134I	1.2	2.45	1.62	15.32	16.60±0.34	3	25	20.37±0.12	4.53±0.01	0.70	2
O8227	(248227) 2005 ES207	2.60	0.11	27.65	306.4	53.8	K134I	5.7 <sup>w</sup>	2.74	1.88	12.25	15.13±0.16	3	29	19.41±0.06	5.88±0.03	0.38	2
O8801	(248801) 2006 SJ122	2.99	0.07	14.15	299.6	96.1	K13B4	6.0 <sup>w</sup>	2.95	2.15	12.99	15.44±0.22	3	38	20.16±0.11	4.67±0.07	0.34	2
P0071	(250071) 2002 EO89	3.20	0.13	9.14	299.9	273.3	K134I	6.9 <sup>w</sup>	3.18	2.40	12.44	14.90±0.20	4	34	20.05±0.09	5.22±0.03	0.25	2
T1120	(291120) 2005 YP199	2.33	0.08	5.91	116.8	11.0	K13B4	0.9	2.15	1.35	19.42	17.22±0.33	3	37	20.36±0.13	7.54±0.06	0.71	2
T8305	(298305) 2003 DO	2.26	0.10	6.05	325.4	220.3	K134I	0.9	2.12	1.25	16.47	17.20±0.29	2	38	20.14±0.10	4.50±0.01	0.66	3
U3486	(303486) 2005 EJ71	2.57	0.11	8.06	121.1	100.6	K134I	2.1	2.58	1.74	14.26	16.40±0.19	2	27	20.50±0.13	2.78±0.01	0.41	2
V3847	(313847) 2004 EF32	2.85	0.08	13.96	295.6	214.5	K134I	4.9	2.65	1.89	16.22	15.29±0.37	4	35	19.64±0.10	2.98±0.01	0.64	2
V5369	(315369) 2007 VG6	5.23	0.09	12.62	304.1	192.3	K13B4	12.3	4.78	3.97	7.57	13.32±0.39	4	58	20.22±0.12	9.30±0.04	0.93	3
Y3002	(343002) 2009 BL76	2.64	0.16	13.77	128.3	303.0	K134I	2.6	2.35	1.51	16.02	15.89±0.32	4	40	19.47±0.07	3.97±0.00	0.80	3



Table 2—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
Y9755	(349755) 2009 AE2	2.45	0.10	7.03	123.1	334.2	K134I	1.3	2.23	1.43	18.35	16.51±0.28	2	33	20.00±0.11	8.47±0.07	0.48	2

Note. — Columns: asteroid’s designations, semimajor axis ( $a$ , AU), eccentricity ( $e$ , degree), inclination ( $i$ , degree), longitude of the ascending node ( $\Omega$ , degree), argument of periapsis ( $\omega$ , degree), epoch, derived diameter (D, km), heliocentric distance ( $\Delta$ , AU), geodesic distance ( $r$ , AU), phase angle ( $\alpha$ , degree), absolute magnitude ( $H$ , mag), number of nights (n), number of images (m),  $PTF_R$  magnitude, derived rotation period (hours), lightcurve amplitude (mag) and rotation period quality code (U). The amplitudes of the objects of partial lightcurve coverage and single minimum lightcurve should be treated as low limits.

\*The asteroids have published rotation periods.

†The objects of partial lightcurve coverage.

∨The objects of single minimum lightcurve.

∞The *WISE*/NEOWISE diameter.

Table 3. The 49 bright PTF detected asteroids with  $U \leq 1$ .

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
01004	(1004) Belopolskya	3.40	0.09	2.98	153.6	216.3	K134I	74.0	3.44	2.71	12.56	9.41±0.08	4	63	15.00±0.00	9.06±0.03	0.12	1
01780	(1780) Kippes	3.02	0.05	9.00	291.0	339.8	K134I	31.3 <sup>w</sup>	3.17	2.54	15.39	10.15±0.06	4	59	15.53±0.01		0.11	
01986	(1986) Plaut	3.09	0.20	2.21	146.6	230.8	K134I	19.6 <sup>w</sup>	3.02	2.28	14.37	11.82±0.07	3	31	16.83±0.01	13.62±0.54	0.16	1
02264	(2264) Sabrina	3.13	0.17	0.16	240.3	79.1	K134I	37.3 <sup>w</sup>	3.60	2.85	11.62	10.50±0.10	4	50	16.30±0.01		0.19	
02273	(2273) Yarilo	2.45	0.17	0.39	66.1	41.5	K134I	5.6 <sup>w</sup>	2.06	1.21	18.71	13.50±0.07	4	65	16.46±0.01		0.10	
02668	(2668) Tataria	2.32	0.08	3.16	298.2	62.9	K134I	5.4 <sup>w</sup>	2.37	1.69	20.82	13.22±0.25	4	50	17.24±0.02		0.53	
03187	(3187) Dalian	2.28	0.06	2.76	312.4	105.1	K134I	6.2 <sup>w</sup>	2.21	1.44	19.78	13.02±0.11	4	54	16.53±0.01		0.22	
03462	(3462) Zhouguangzhao	2.45	0.21	5.80	113.1	254.9	K134I	5.5	2.46	1.77	19.41	13.32±0.40	4	42	17.42±0.02		0.75	
03935	(3935) Toatenmongakkai	2.54	0.23	8.75	300.5	104.4	K134I	11.2 <sup>w</sup>	2.24	1.49	20.26	11.78±0.42	4	49	15.43±0.01		1.08	
04890	(4890) Shikanosima	2.20	0.15	3.66	100.3	185.5	K134I	4.7 <sup>w</sup>	2.52	1.70	15.46	13.52±0.11	4	45	17.52±0.01		0.21	
04929	(4929) Yamatai	2.21	0.06	2.49	127.5	89.9	K134I	4.0 <sup>w</sup>	2.22	1.42	19.08	14.04±0.07	2	36	17.50±0.02	3.62±0.06	0.14	1
05005	(5005) Kegler	2.25	0.17	1.31	320.7	108.7	K134I	3.5 <sup>w</sup>	1.98	1.18	21.69	14.61±0.10	4	35	17.52±0.02		0.31	
05045	(5045) Hoyin	3.13	0.19	2.57	130.7	262.5	K134I	17.1	3.00	2.16	11.96	12.60±1.30	4	40	17.60±0.02		0.47	
05199	(5199) Dortmund	2.62	0.18	12.27	295.7	343.1	K134I	9.8 <sup>w</sup>	3.06	2.30	13.65	11.77±0.14	4	46	16.84±0.01		0.23	
06331	(6331) 1992 FZ1	2.36	0.13	7.77	129.5	190.0	K134I	5.3 <sup>w</sup>	2.65	1.83	14.23	12.82±0.14	4	48	17.08±0.01		0.15	
06503	(6503) 1994 CP	2.85	0.04	2.93	135.4	264.4	K134I	12.9	2.82	2.04	14.53	13.21±0.43	4	37	17.82±0.02	7.13±0.05	0.23	1
06615	(6615) Plutarchos	2.17	0.13	1.80	129.4	81.2	K134I	3.1 <sup>w</sup>	2.15	1.40	21.27	14.45±0.11	4	56	17.90±0.02		0.14	
07120	(7120) Davidgavine	2.86	0.06	1.16	314.2	91.5	K134I	14.1	2.79	2.06	15.96	13.01±0.21	4	55	17.68±0.02	1.44±0.00	0.19	1
07205	(7205) Sadanori	2.63	0.12	1.68	274.6	337.3	K134I	5.3 <sup>w</sup>	2.85	2.13	15.70	12.81±0.26	4	54	17.58±0.02		0.14	
07712	(7712) 1995 TB1	2.57	0.24	4.86	134.6	255.1	K134I	4.1 <sup>w</sup>	2.41	1.63	17.52	13.48±0.09	4	54	17.36±0.02		0.16	
08122	(8122) Holbein	2.38	0.16	1.54	302.4	178.8	K134I	3.5 <sup>w</sup>	1.99	1.14	19.30	14.30±0.09	4	59	17.05±0.01		0.17	
08434	(8434) Columbianus	2.97	0.25	3.13	118.2	336.6	K134I	10.3 <sup>w</sup>	2.26	1.52	20.36	13.52±0.15	4	51	17.21±0.01		0.39	
09072	(9072) 1993 RX3	3.21	0.07	15.23	290.1	14.7	K134I	25.3 <sup>w</sup>	3.43	2.75	13.35	11.64±0.09	4	47	17.30±0.01		0.15	
09358	(9358) Faro	2.64	0.09	3.30	126.8	217.5	K134I	5.7 <sup>w</sup>	2.82	1.95	11.35	13.22±0.09	4	43	17.62±0.02		0.18	

Table 3—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
09629	(9629) Servet	2.71	0.05	1.80	330.2	96.6	K134I	8.4	2.62	1.76	12.92	13.39±0.10	4	48	17.47±0.02		0.20	
09813	(9813) Rozgaj	2.27	0.13	1.62	201.8	227.3	K134I	3.8 <sup>w</sup>	2.07	1.28	20.88	14.07±0.08	4	58	17.24±0.01		0.11	
10361	(10361) Bunsen	2.29	0.12	3.64	143.5	286.4	K134I	2.4 <sup>w</sup>	2.09	1.31	21.08	14.10±0.13	4	46	17.37±0.02		0.14	
11181	(11181) 1998 FG118	3.04	0.05	3.97	296.1	246.2	K134I	15.9 <sup>w</sup>	2.97	2.12	11.52	12.32±0.20	4	56	17.01±0.01		0.40	
11215	(11215) 1999 HN10	2.97	0.10	0.64	256.7	109.7	K134I	15.9	3.04	2.29	13.85	12.76±0.18	4	54	17.71±0.02		0.27	
11664	(11664) Kashiwagi	3.18	0.08	2.74	117.4	78.9	K134I	12.0 <sup>w</sup>	3.09	2.26	11.55	13.01±0.12	4	46	17.93±0.03		0.25	
13323	(13323) 1998 SQ	5.12	0.09	0.92	182.5	256.2	K134I	23.4 <sup>w</sup>	4.76	3.91	6.88	10.84±0.13	4	61	17.63±0.02	13.48±0.33	0.17	1
13529	(13529) Yokaboshi	2.24	0.10	4.36	312.7	173.6	K134I	4.6	2.03	1.17	18.41	13.72±0.09	4	55	16.57±0.01		0.27	
14973	(14973) Rossirosina	2.77	0.07	4.48	302.5	148.9	K134I	7.4	2.60	1.84	16.60	13.66±0.19	4	38	17.90±0.02		0.31	
16462	(16462) 1990 DZ1	2.46	0.09	5.94	315.7	180.0	K134I	4.4 <sup>w</sup>	2.25	1.41	17.13	13.53±0.34	4	48	16.78±0.01		0.23	
16952	(16952) Peteschultz	3.10	0.08	4.07	137.0	321.5	K134I	9.0 <sup>w</sup>	2.86	2.02	12.37	13.28±0.09	4	49	17.84±0.02		0.22	
17627	(17627) Humptydumpty	3.20	0.15	0.95	150.3	308.1	K134I	13.9	2.74	1.96	15.03	13.04±0.14	4	45	17.48±0.02		0.21	
18163	(18163) Jennalewis	2.38	0.14	5.25	134.6	313.4	K134I	2.9	2.08	1.27	19.62	14.71±0.20	4	43	17.85±0.02		0.44	
18485	(18485) 1996 AB	3.19	0.14	2.54	298.6	133.4	K134I	13.0 <sup>w</sup>	2.88	2.04	12.46	13.28±0.19	4	54	17.88±0.02		0.41	
18947	(18947) Cindyfulton	2.39	0.14	2.00	328.1	156.6	K134I	3.4 <sup>w</sup>	2.06	1.17	16.35	14.94±0.35	4	57	17.83±0.02		0.81	
19342	(19342) 1997 AA7	2.53	0.23	2.78	136.0	283.2	K134I	4.8	2.18	1.35	17.49	14.61±0.14	4	55	17.94±0.02		0.25	
19717	(19717) 1999 UZ40	2.55	0.13	2.06	123.6	83.6	K134I	6.8	2.49	1.69	16.38	13.83±0.13	4	31	17.84±0.02		0.35	
20063	(20063) 1993 RC4	3.22	0.07	3.98	313.5	242.6	K134I	11.3 <sup>w</sup>	3.13	2.26	9.97	12.93±0.11	4	40	17.81±0.02		0.17	
27716	(27716) Nobuyuki	2.86	0.24	6.04	123.9	359.1	K13B4	6.3 <sup>w</sup>	2.17	1.32	16.76	13.71±0.24	4	61	16.83±0.01		0.26	
29514	(29514) Karatsu	2.94	0.16	15.31	293.1	242.9	K134I	10.4 <sup>w</sup>	2.63	1.86	15.93	13.21±0.15	4	46	17.57±0.02		0.25	
30872	(30872) 1992 EM17	2.33	0.11	5.06	128.2	86.0	K134I	3.1 <sup>w</sup>	2.30	1.47	16.69	13.95±0.10	3	40	17.47±0.02		0.09	
31025	(31025) 1996 GR	2.30	0.15	2.69	97.6	85.3	K134I	2.5 <sup>w</sup>	2.06	1.18	16.50	15.04±0.16	4	52	17.88±0.02	19.20±0.52	0.19	1
56070	(56070) 1998 YQ5	2.31	0.11	2.57	311.8	131.1	K134I	2.5 <sup>w</sup>	2.10	1.26	18.35	14.66±0.18	4	53	17.75±0.02		0.48	
69485	(69485) 1997 AD	2.53	0.15	11.89	294.3	237.4	K134I	4.3 <sup>w</sup>	2.28	1.56	20.55	13.94±0.15	4	46	17.69±0.02		0.27	

Table 3—Continued

Obj ID	Designation	$a$	$e$	$i$	$\Omega$	$\omega$	Epoch	D	$\Delta$	$r$	$\alpha$	$H$	n	m	$PTF_R$	Period (hr)	$\Delta m$	U
A3557	(103557) 2000 BK28	2.65	0.36	6.51	115.8	308.5	K134I	4.2	1.95	1.12	20.75	14.88±0.30	4	42	17.50±0.02		0.41	

Note. — Columns: asteroid’s designations, semimajor axis ( $a$ , AU), eccentricity ( $e$ , degree), inclicnation ( $i$ , degree), longitude of the ascending node ( $\Omega$ , degree), argument of periapsis ( $\omega$ , degree), epoch, derived diameter (D, km), heliocentric distance ( $\Delta$ , AU), geodesic distance ( $r$ , AU), phase angle ( $\alpha$ , degree), absolute magnitude ( $H$ , mag), number of nights (n), number of images (m),  $PTF_R$  magnitude, derived rotation period (hours), lightcurve varition (mag) and rotation period quality code (U).

<sup>w</sup>The *WISE*/NEOWISE diameter.

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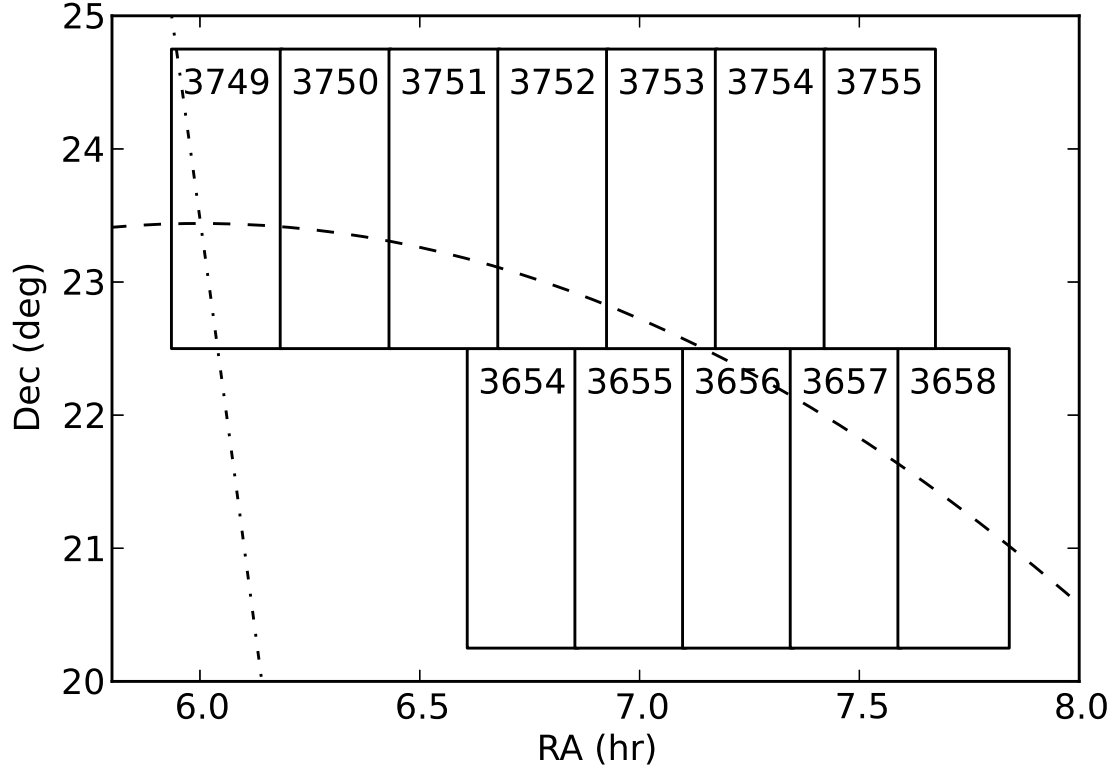


Fig. 1.— The configuration of 12 PTF fields. Each rectangular represents a PTF field with an field ID on top. The field of view of each PTF field is  $3.50^\circ \times 2.31^\circ \sim 7.26 \text{ deg}^2$ . The dashed and dot-dashed lines show the ecliptic and Galactic planes, respectively. Note that the scales of R.A. and Declination are not in proper ratio.



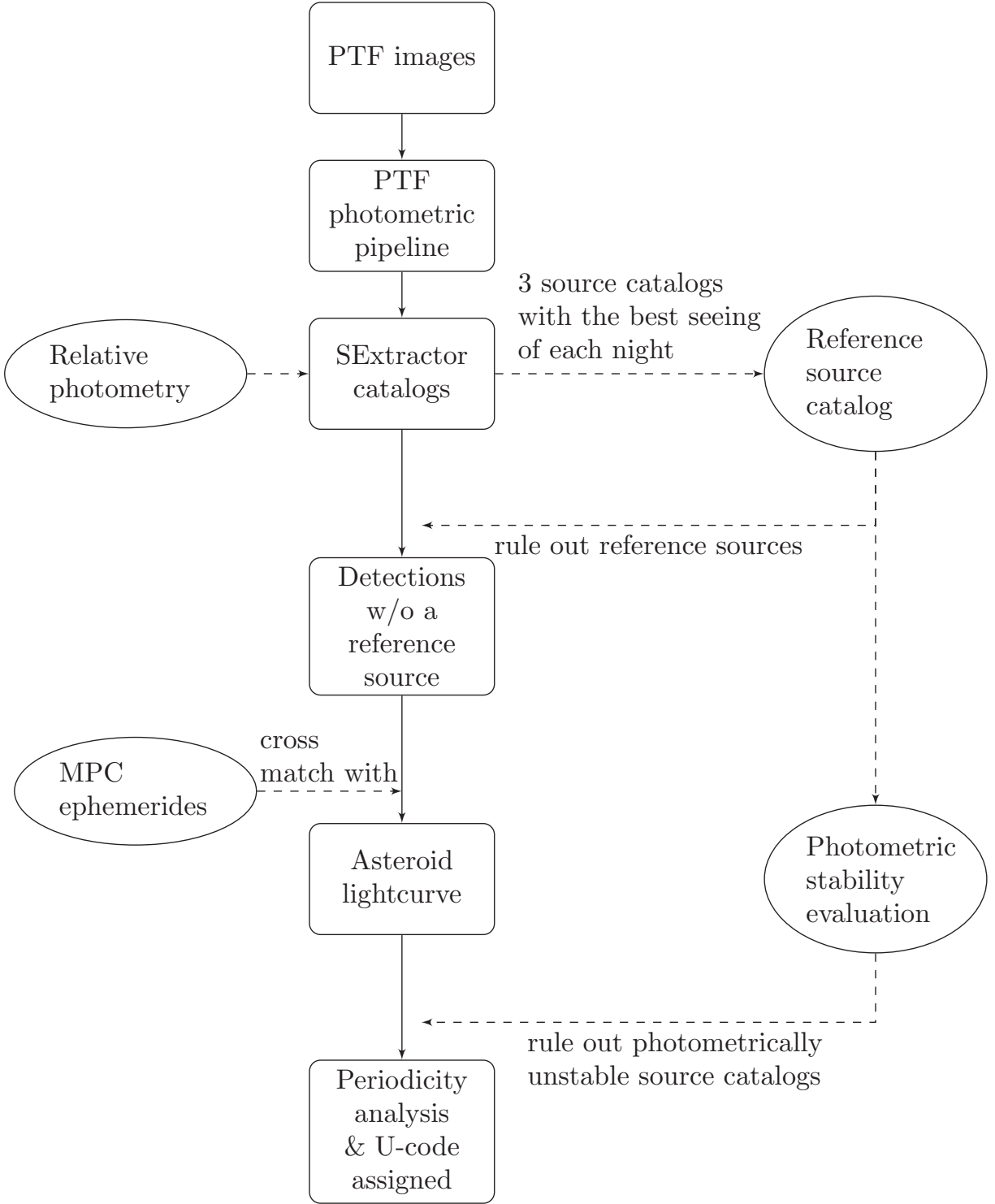


Fig. 2.— The data process flow chart. See section 3 for explanation.

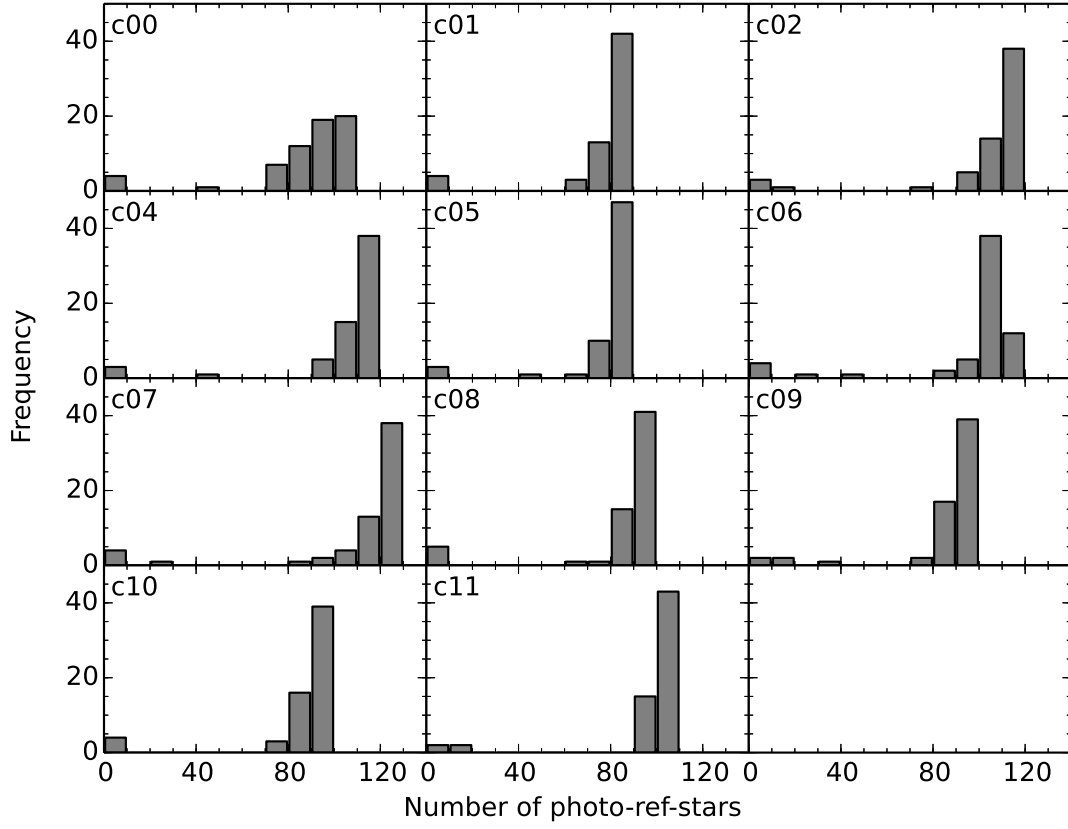


Fig. 3.— The number distribution of photo-ref-stars of  $17.5 < R < 17.6$  mag for each CCD in field 3655. The CCD numbers are shown on the upper-left corner of each plot.

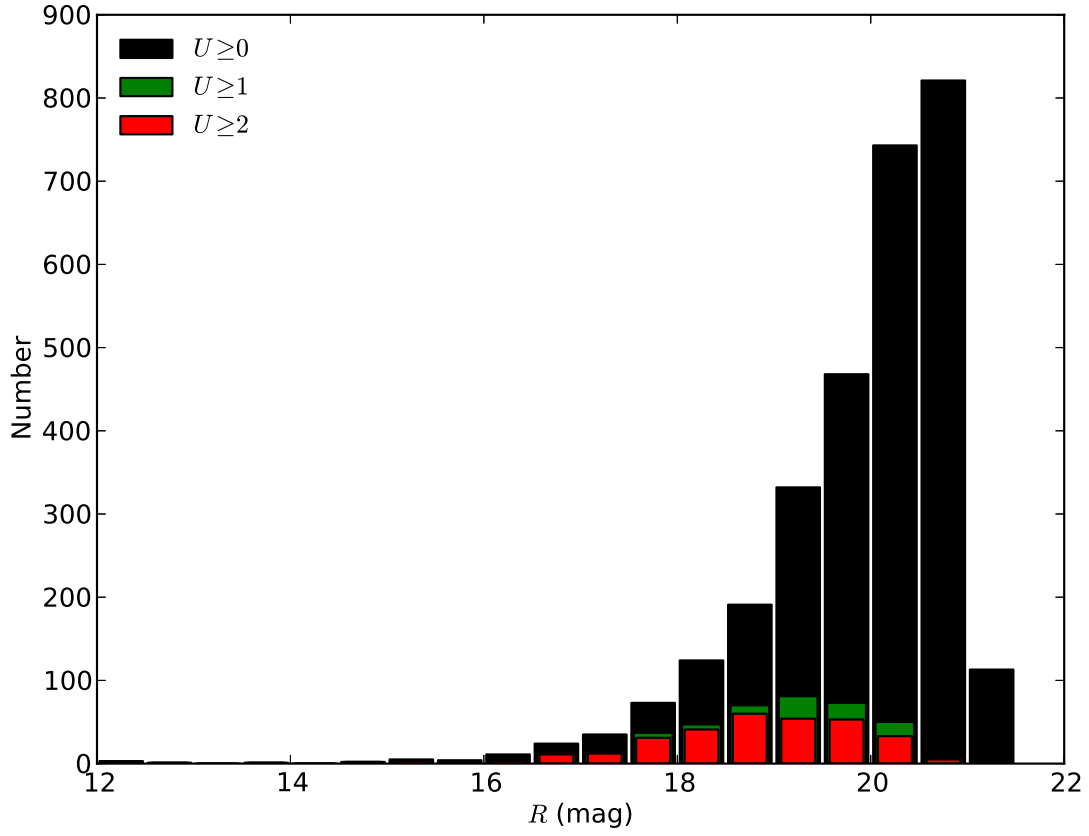


Fig. 4.— The distributions of magnitudes of the PTF detected asteroids. Black, green and red represent rotation periods of  $U \geq 0$ ,  $U \geq 1$  and  $U \geq 2$ , respectively.

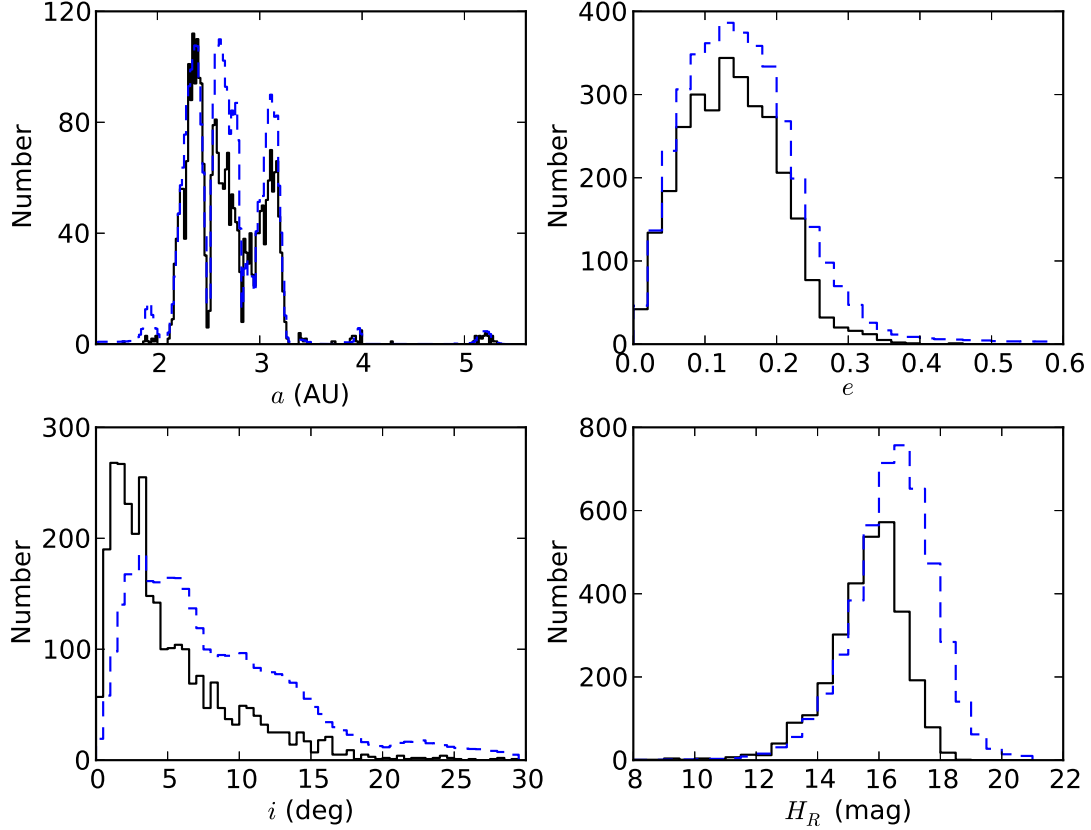


Fig. 5.— The distributions of orbital elements for the PTF detected asteroids (solid line) along with that of known asteroids with  $a < 6$  AU in arbitrary normalization (dashed line). From the upper-left to the lower-right panels are the distributions for semimajor axes ( $a$ , 0.02 AU bins), eccentricities ( $e$ , 0.01 bins), inclinations ( $i$ ,  $0.5^\circ$  bins) and absolute magnitudes ( $H_R$ , 0.3 mag bins).

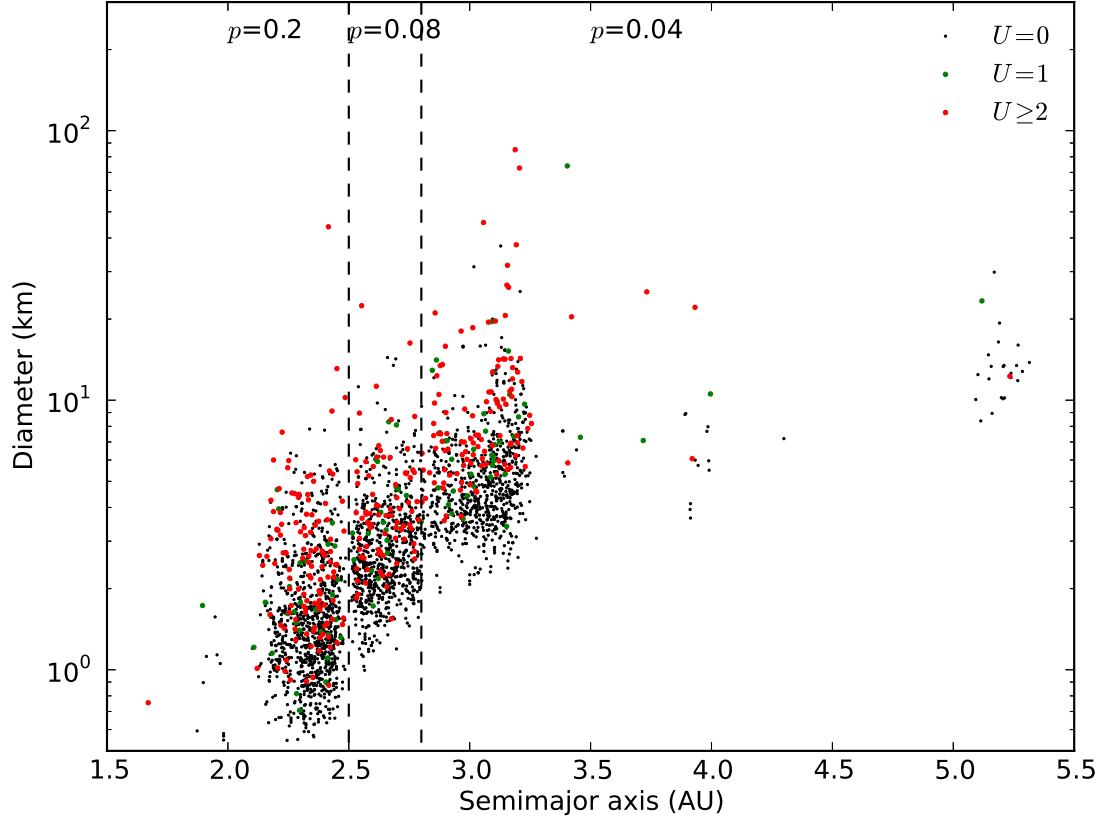


Fig. 6.— The plot of the diameter vs. semimajor axis for the PTF detected objects. The red, gray and black filled circles represent rotation periods of  $U = 0$ ,  $U = 1$  and  $U \leq 2$ , respectively. The dashed lines show the semimajor axis ranges for different empirical values of geometric albedo ( $p$ ).

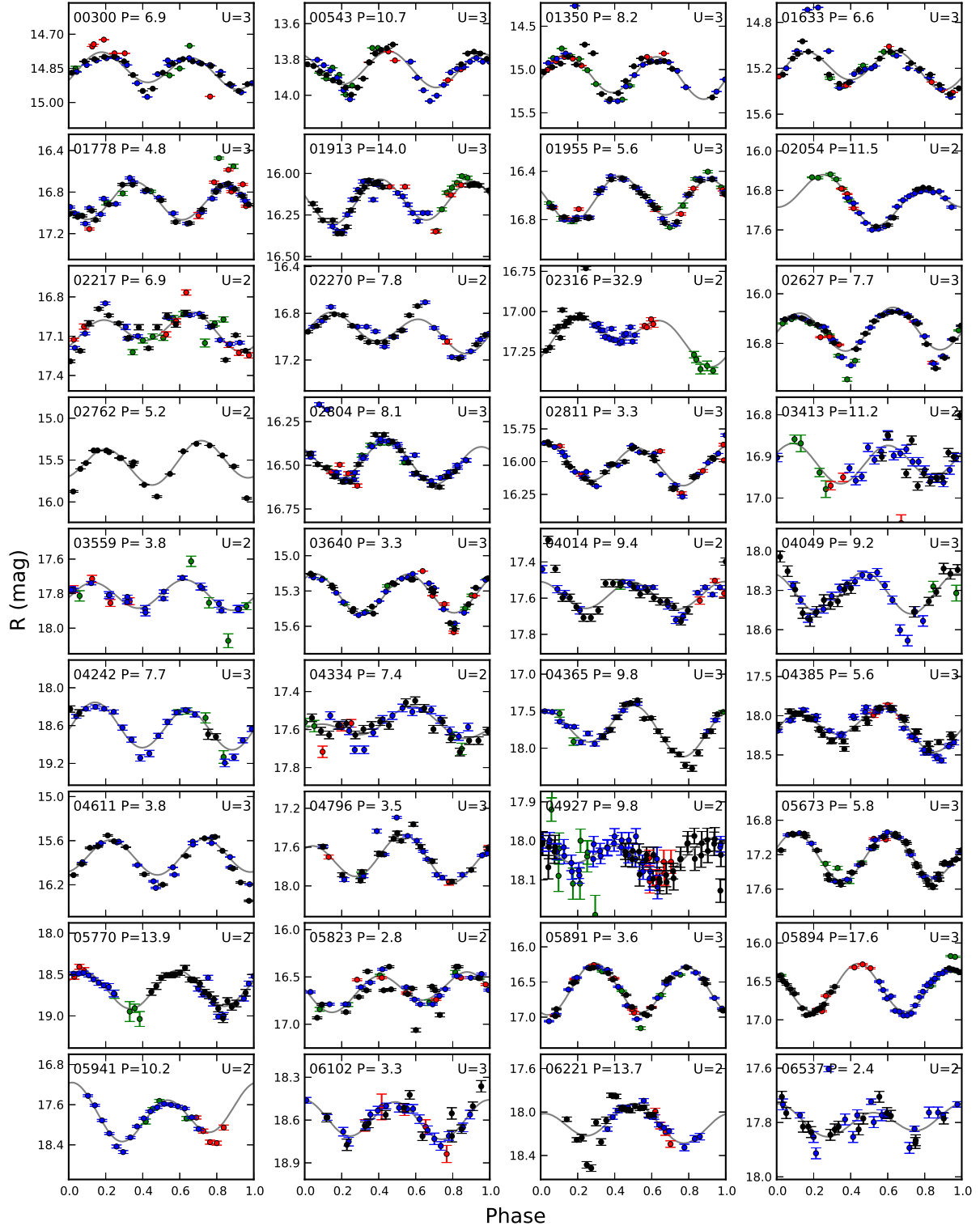


Fig. 7.— Set of 36 folded lightcurves for the PTF-U2 asteroids. The green, red, blue and black circles represent the observation date of February 15, 16, 17 and 18, 2013, respectively.

The designation, rotation period in hours ( $P$ ) and the quality code  $U$  of each object are

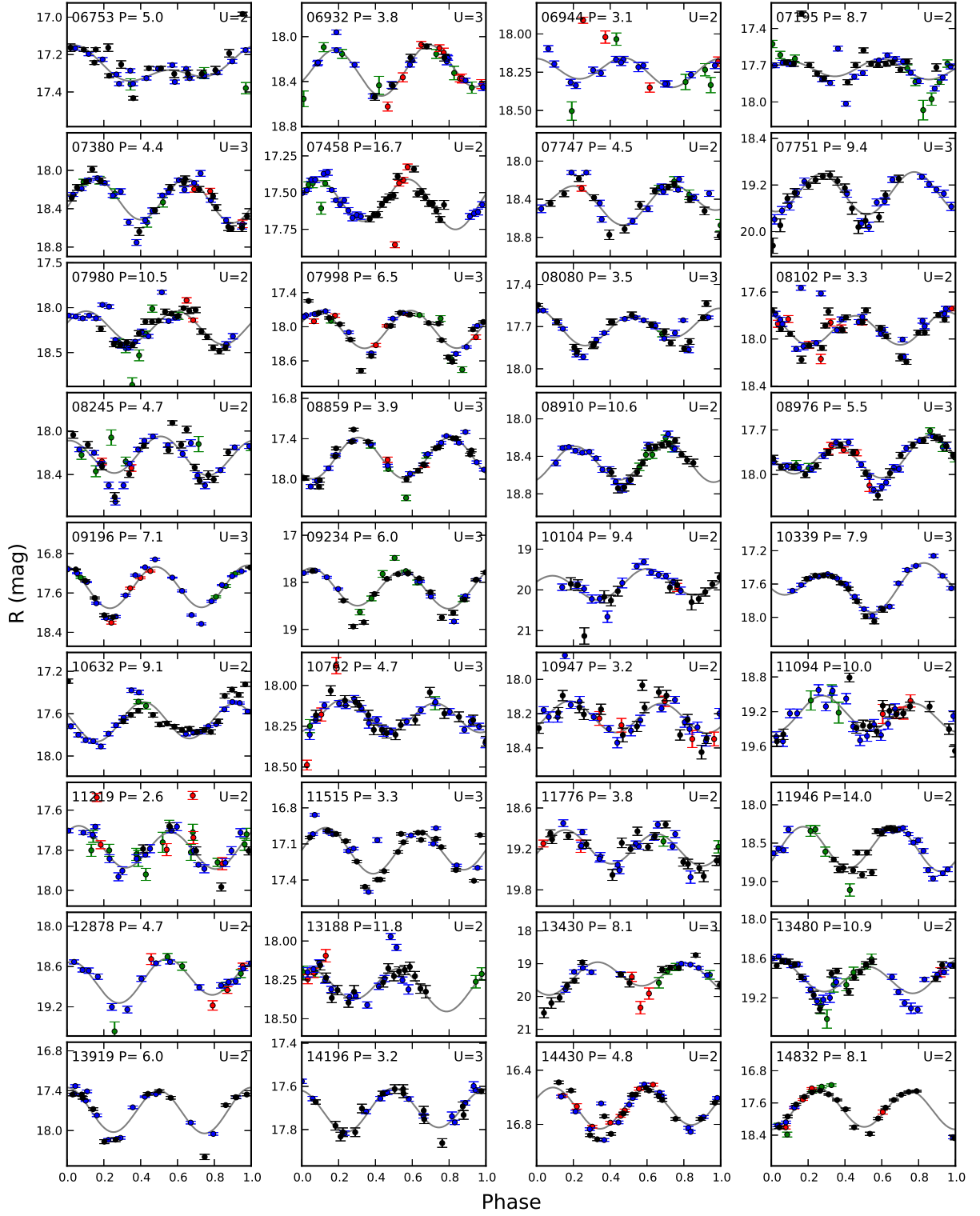


Fig. 8.— Same as Fig. 7 for 36 more PTF-U2 asteroids.

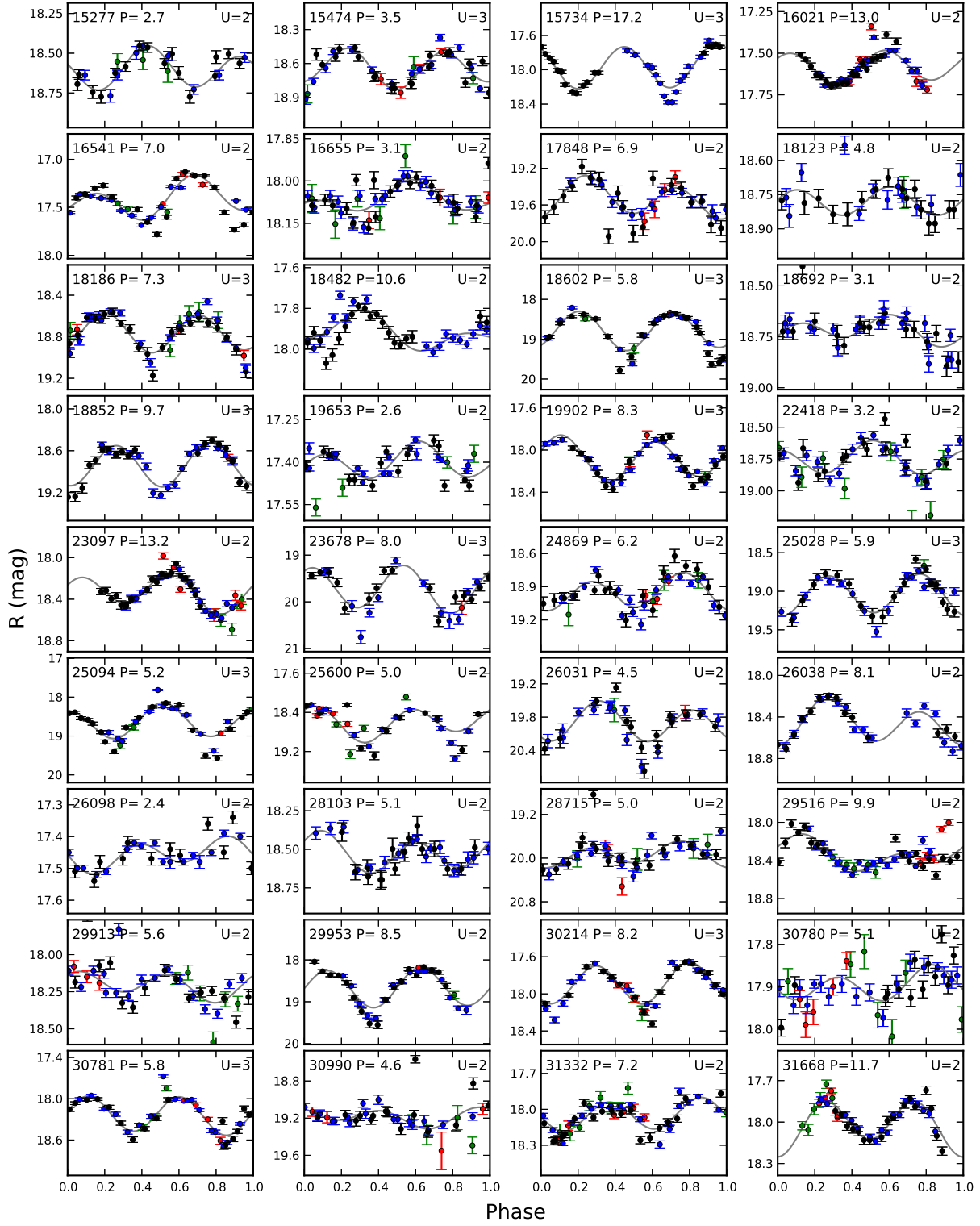


Fig. 9.— Same as Fig. 7 for 36 more PTF-U2 asteroids.



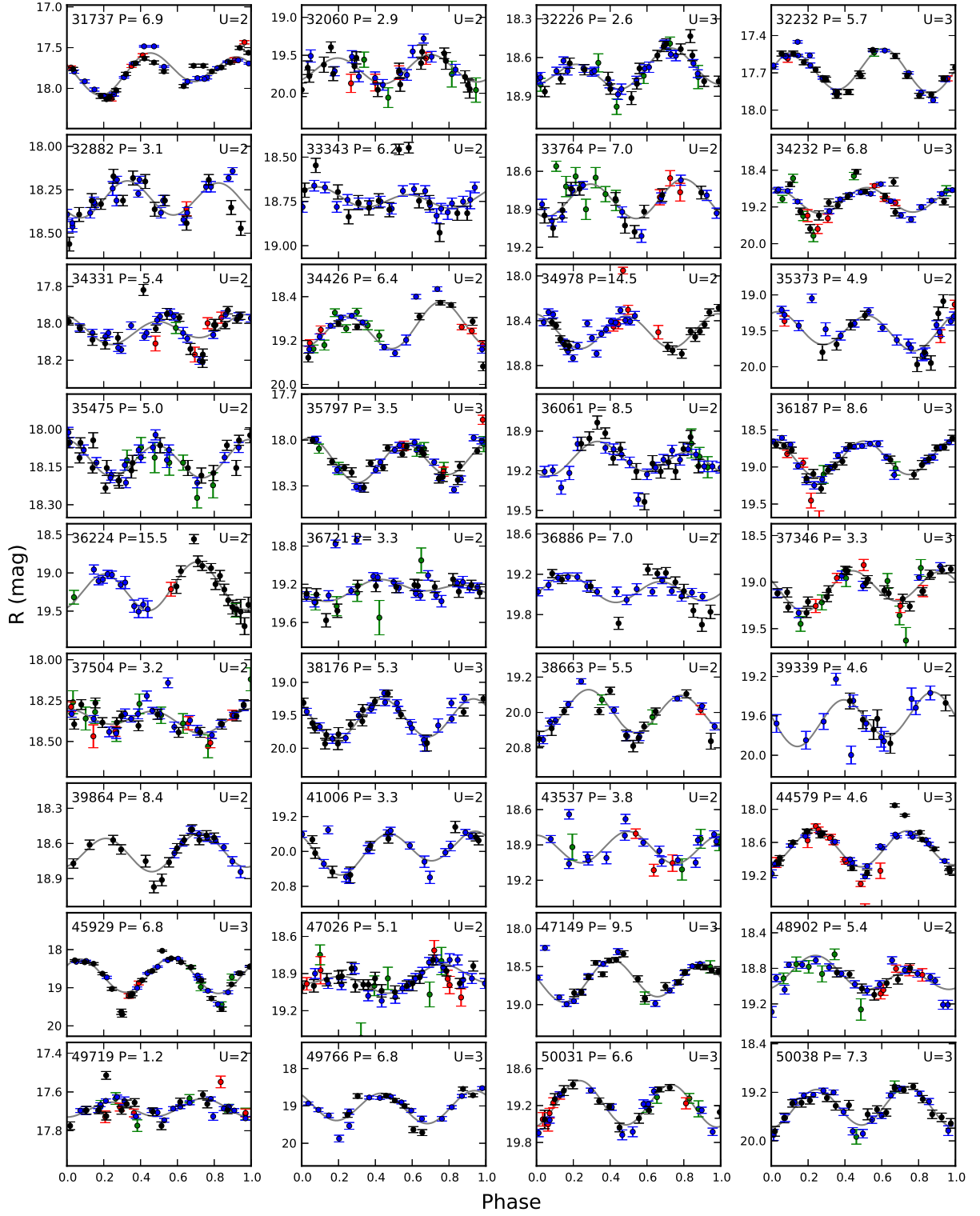


Fig. 10.— Same as Fig. 7 for 36 more PTF-U2 asteroids.

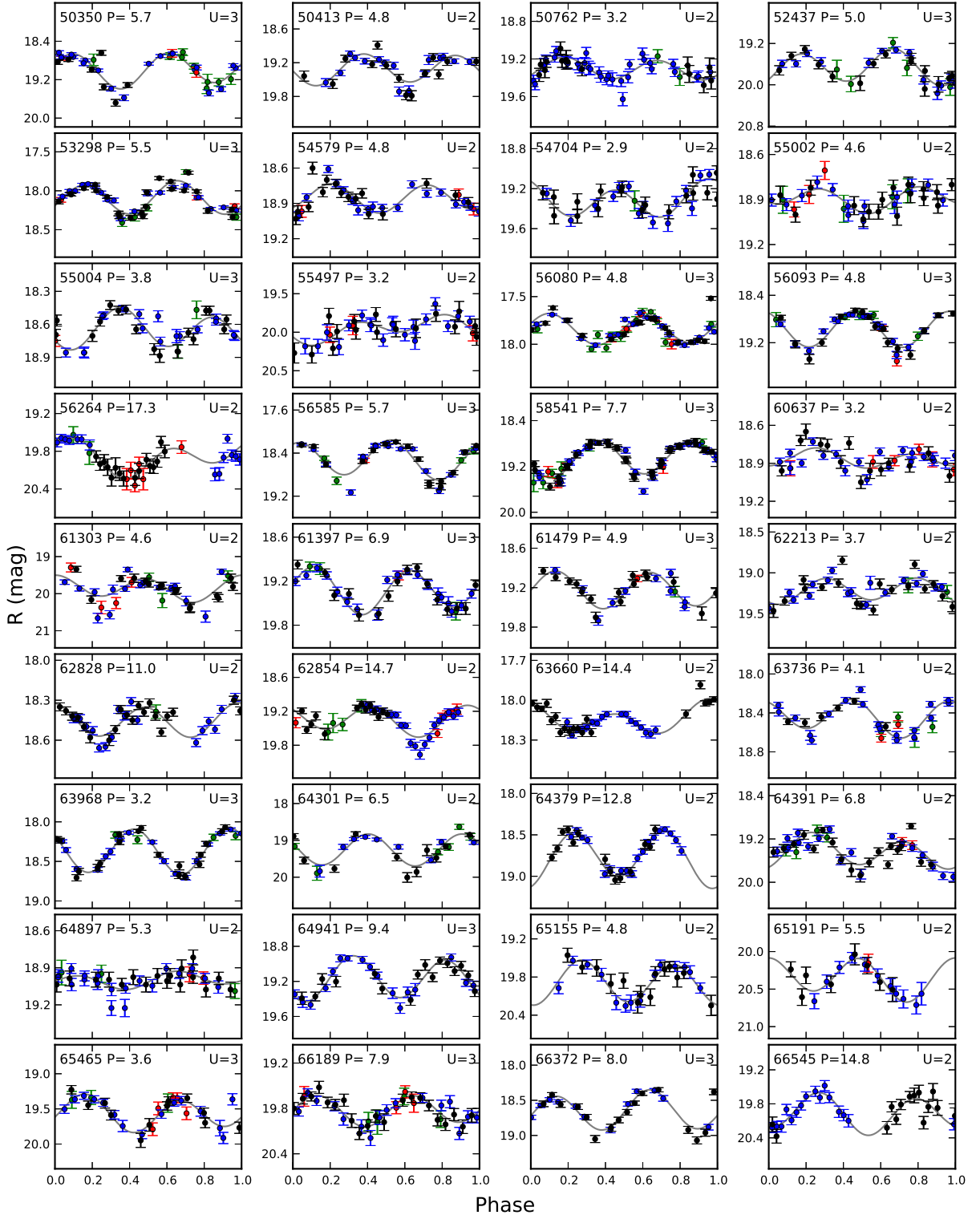


Fig. 11.— Same as Fig. 7 for 36 more PTF-U2 asteroids.

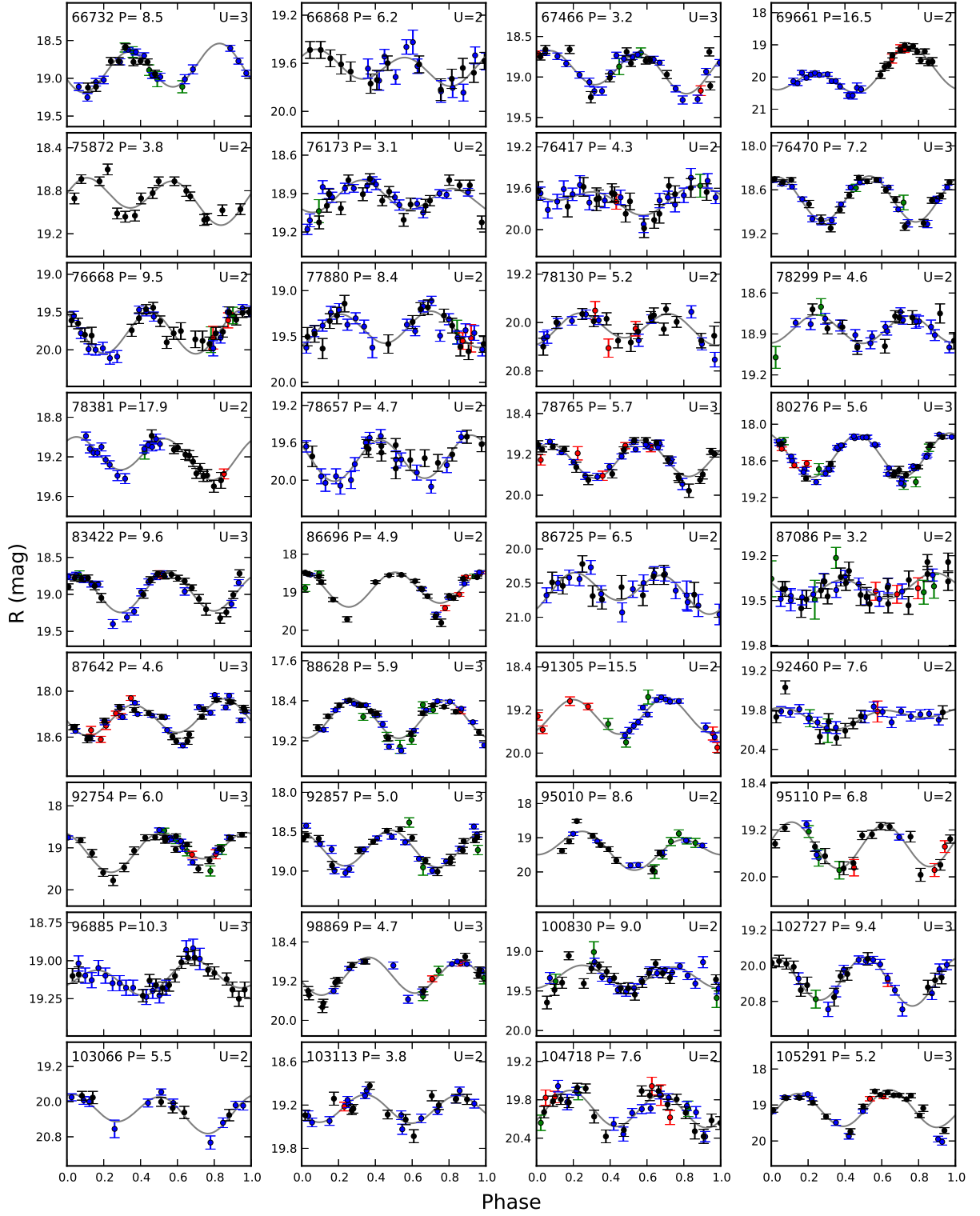


Fig. 12.— Same as Fig. 7 for 36 more PTF-U2 asteroids.

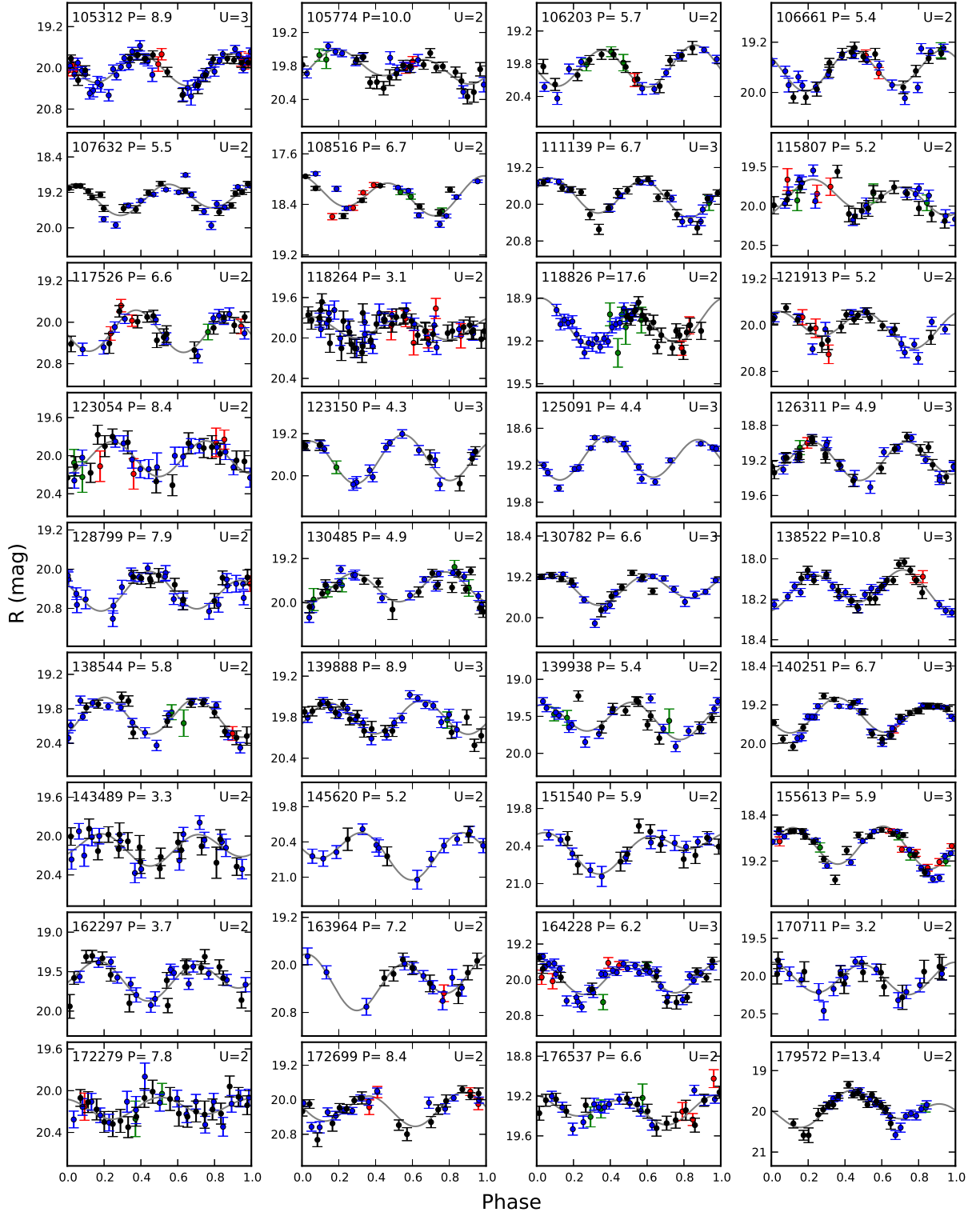


Fig. 13.— Same as Fig. 7 for 36 more PTF-U2 asteroids.

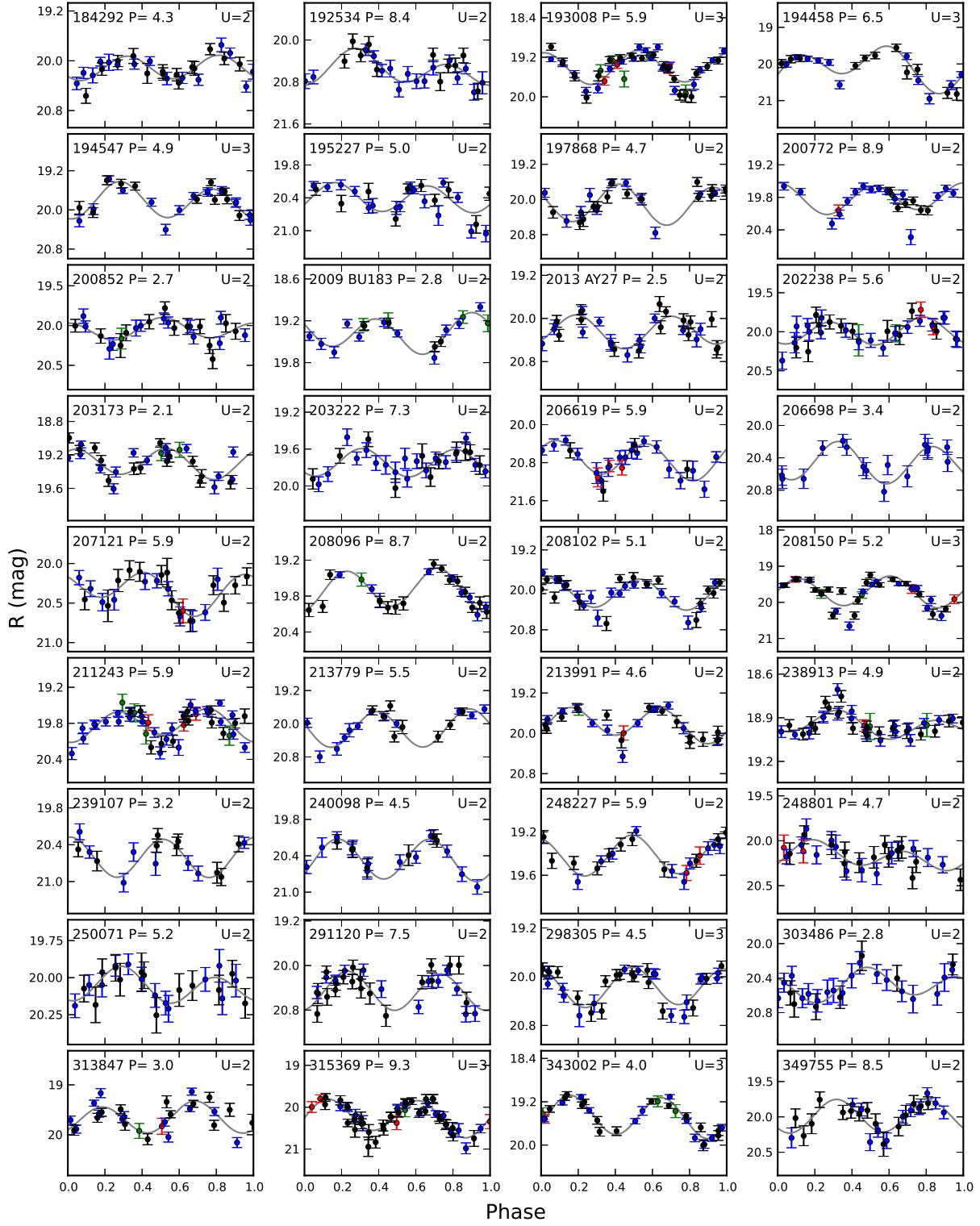


Fig. 14.— Same as Fig. 7 for 36 more PTF-U2 asteroids.

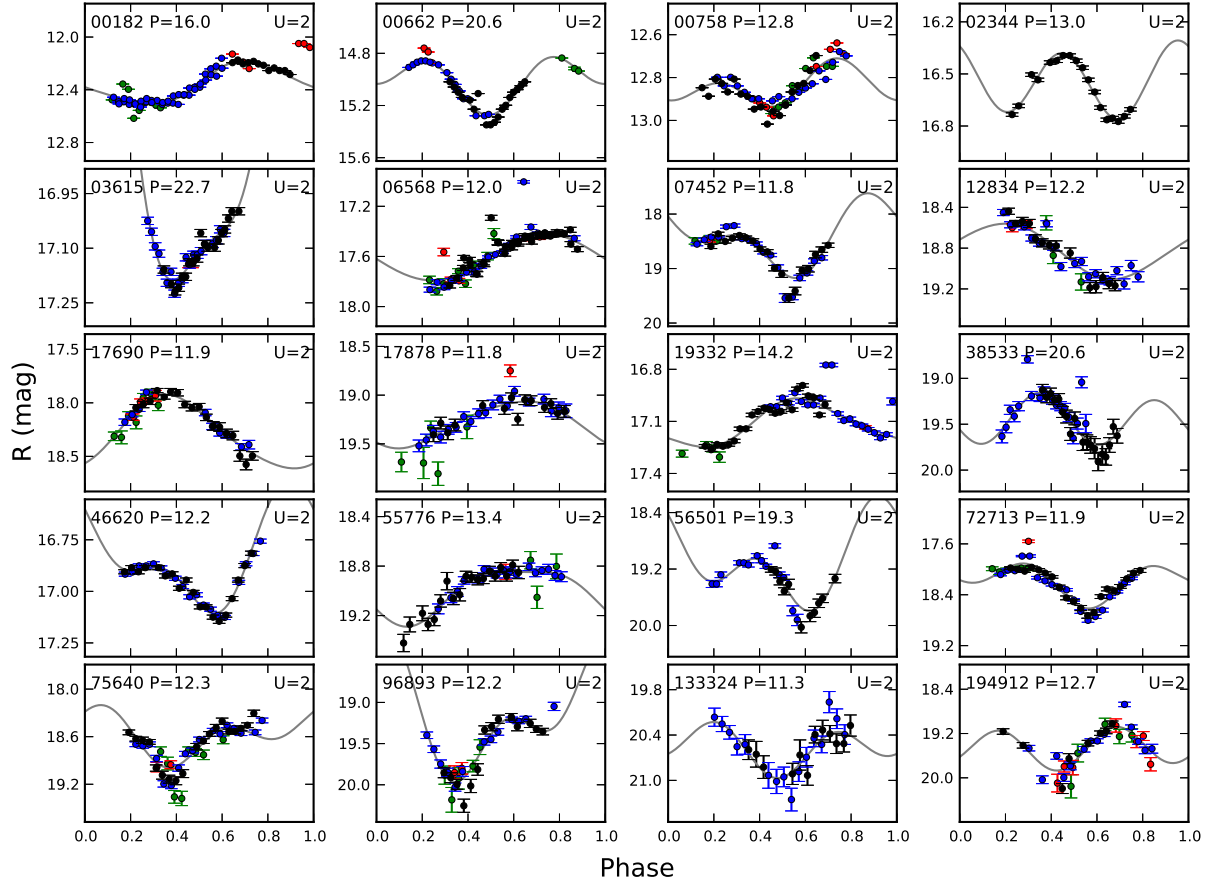


Fig. 15.— Same as Fig. 7 for 20 more PTF-U2 asteroids, whose folded lightcurves only cover part of a rotation period. (7452) Izabelyuria and (75640) 2000 AE55 show binary asteroid features.

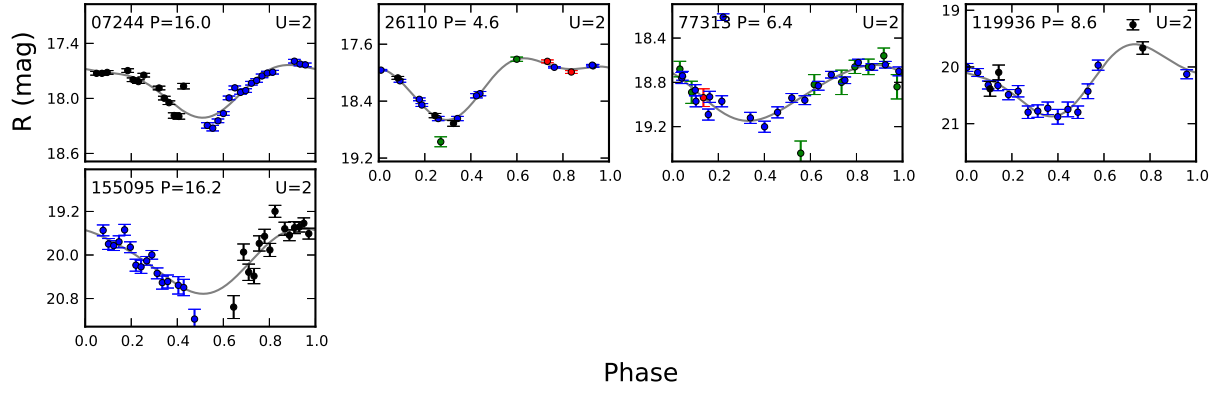


Fig. 16.— Same as Fig. 7 for five more PTF-U2 asteroids, whose folded lightcurves show a single minimum.

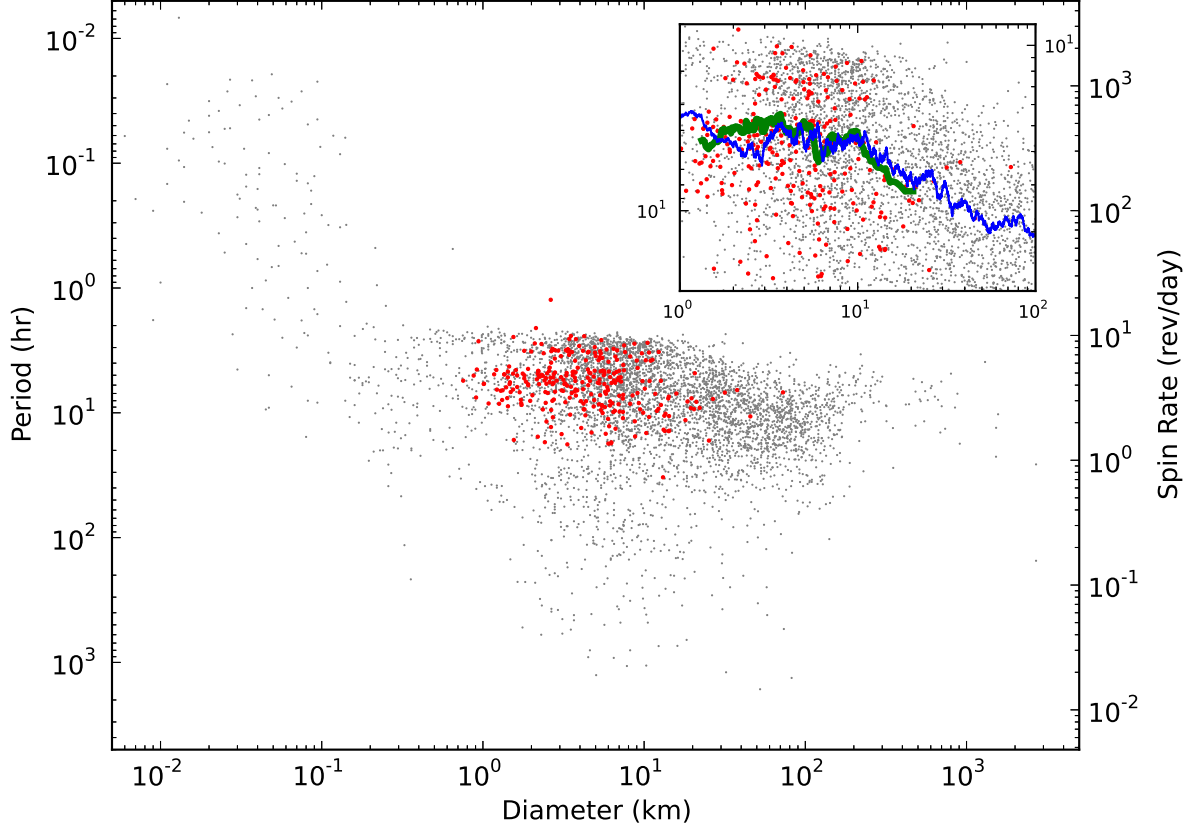


Fig. 17.— The plot of the diameters vs. rotation period. The red and gray filled circles are the PTF-U2 asteroids and the LCDB objects with  $U \geq 2$ , respectively. The distribution of the PTF-U2 asteroids and that of the LCDB are similar. The “spin barrier” at  $\sim 2.2$  hours can obviously be seen for asteroids with diameters larger than a few hundred meters. The red filled circle above the “spin barrier” is the super faster rotator candidate, (49719) 1999 VE50. The small plot at the upper-right corner is the detailed view of the dense region, where the green and blue lines are the geometric mean spin rates of the PTF-U2 asteroids and the LCDB, respectively



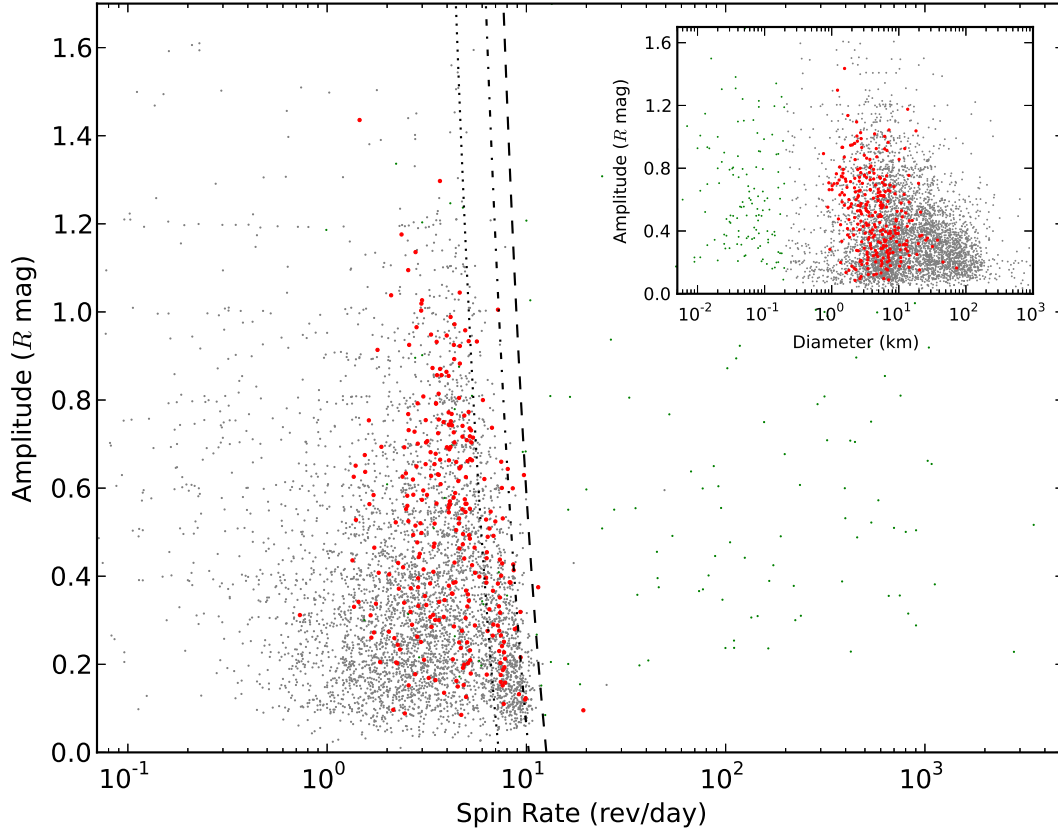


Fig. 18.— The plot of the spin rate vs. diameter. The red, gray and green filled circles are the PTF-U2 asteroids, the LCDB objects with  $D \geq 0.2$  km and the LCDB objects with  $D < 0.2$  km, respectively. The dashed, dot-dashed and dotted lines represent the spin rate limits for “rubble pile” asteroids with bulk densities of 3, 2 and 1 g/cm<sup>3</sup> adopted from Pravec & Harris (2000). The small plot at the upper-right corner is the plot of the diameter vs. lightcurve amplitude for the PTF-U2 asteroids.

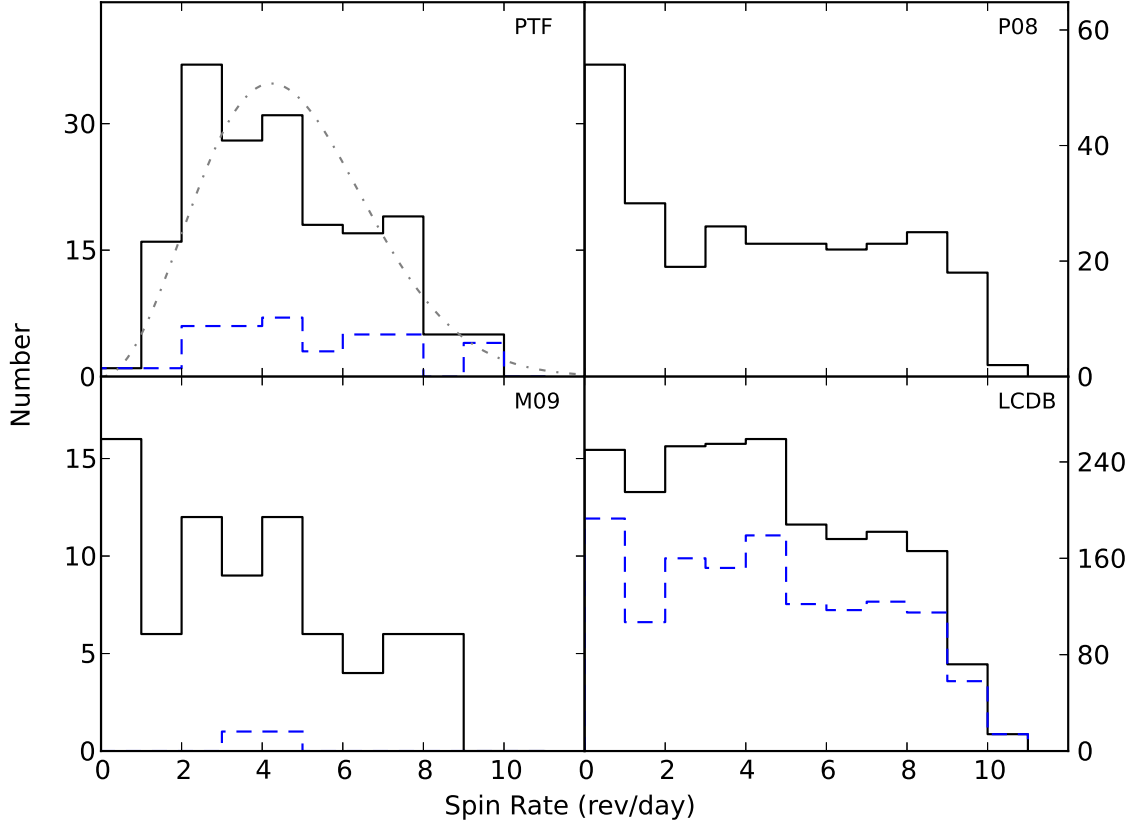


Fig. 19.— The distributions of spin rate of asteroids with  $3 < D \leq 15$  km (solid lines) for the PTF-U2 asteroids (upper-left), P08 (upper-right), M09 (lower-left) and the LCDB. The dashed lines are the asteroids with  $a < 2.5$  AU. The dot-dashed line on the PTF-U2 asteroids is the best-fit Maxwellian distribution.

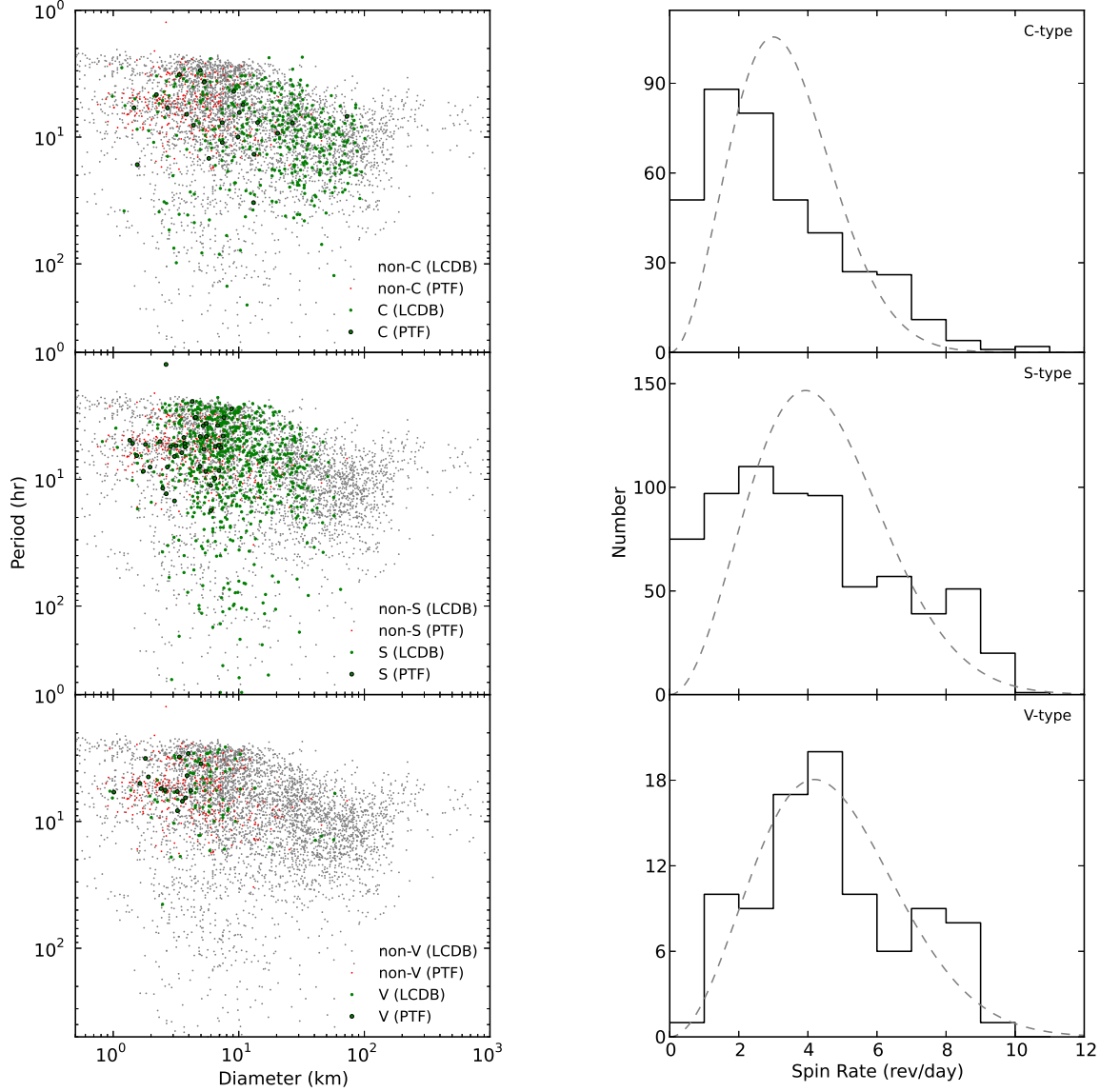


Fig. 20.— Left column: The plots of the diameter vs. rotation period for C- (upper panel), S- (middle panel) and V-type (lower panel) asteroids. The bigger green filled circles with black edge and the smaller green filled circles represent PTF-U2 asteroids and the LCDB objects with available taxonomy, respectively. The red and gray dots are the PTF-U2 asteroids and LCDB objects other than the corresponding taxonomic type in each plot, respectively. The taxonomic types are obtained from SDSS colors. Right column: The distributions of spin rate (solid lines) for C- (upper panel), S- (middle panel) and V-type (lower panel) asteroids.